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HUMBOLDT'S COSMOS.

COSMOS:

A SKETCH

OF A

PHYSICAL DESCRIPTION OF THE UNIVERSE.

BY

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TRANSLATED FROM THE GERMAN,

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Naturæ vero rerum vis atque majestas in omnibus momentis fide caret, si quis modo partes ejus ac non totam complectatur animo.—Plin., *Hist. Nat.*, lib. vii, c. 1.

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GENERAL SUMMARY OF CONTENTS

OF

VOLS. III. AND IV. OF COSMOS.

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HUMBOLDT'S CORRECTIONS AND ADDITIONS

TO VOL. III.

Page 40, line 20.

Since the printing of that part of the *Cosmos*, where a doubt is expressed as to whether it has been "shown with certainty that the positions of the Sun influence the terrestrial magnetism," the new and excellent investigations of Faraday have proved the reality of such an influence. Long series of magnetic observations in opposite hemispheres (*e. g.*, Toronto in Canada, and Hobart Town in Van Diemen's Land), show that the terrestrial magnetism is subject to an annual variation, which depends upon the relative position of the Sun and Earth.

Page 75, line 29.

The remarkable phenomenon of the *undulation* of stars has very recently been observed at Trier by very trustworthy witnesses, in Sirius, between 7 and 8 o'clock, while near the horizon. See the letter of Herrn Flesch, in *Jahn's Unterhaltungen für Freunde der Astronomie.*

Page 178, line 17, note 50.

The wish which I strongly expressed that the historical epoch in which the disappearance of the *red colour of Sirius* falls should be more positively determined, has been partially fulfilled by the laudable industry of Dr. Wöpcke, a young scholar, who combines an excellent acquaintance with Oriental languages with distinguished mathematical knowledge. The translator and commentator of the important *Algebra* of Omar Alkhayyami, writing to me from Paris, in August, 1851, says, "I have examined the four manuscripts in this place of the *Uranography* of Abdurrahman Al-Sufi, in reference to your suggestion contained in the astronomical volume of the *Cosmos*, and found that α Bootis, α Tauri, α Scorpii, and α Orionis, are all expressly called *red;* Sirius, on the contrary, is not. Moreover, the passages referring to it are uniformly as follows in all the four manuscripts :—"The first among its (Great Dog) stars is the large, brilliant one in his mouth, which is represented on the Astrolabium, and is called *Al-jemaanijah.*" Is it not probable from this investigation, and from what I quoted from Alfragani, that the epoch of the change of colour falls between the time of Ptolemæus and the Arabs?

Page 264, line 13.

In the condensed statement of the method by which the parallax of the double stars is found by means of the velocity of light, it should be said: The time which elapses between the moment in which the planetary secondary star is nearest to the Earth, and that in which it is most distant from it is always longer when the star passes from the point of greatest proximity to that of greatest elongation, than in the converse, when it returns from the point of greatest elongation to that of greatest proximity.

Page 289, line 1.

In the French translation of the astronomical volume of the *Cosmos*, which, to my great gratification, M. H. Faye has again undertaken, this learned astronomer has much enriched the section upon double stars. I had myself neglected to make use of the important treatises of M. Yvon Villarceau, which were read at the Institute in the course of the year 1849. (See *Connaissance des Temps pour l'an* 1832, pp. 3—128). I quote here from the table by M. Faye, of the orbital elements of eight double stars, the first four stars, which he considers to be the most certainly determined:—

Elements of the Orbits of Double Stars.

Name and Magnitude.	Semi major axis.	Eccentricity.	Period of revolution in Years.	Name of the Calculator.
ξ Ursæ Majoris, (4th and 5th Mag.)	3″·857	0·4164	58·262	Savary ... 1830
	3″·278	0·3777	60·720	J. Herschel 1849
	2″·295	0·4037	61·300	Mädler ... 1847
	2″·439	0·4315	61·576	Y. Villarceau 1849
p Ophiuchi, (4th and 6th Mag.)	4″·328	0·4300	73·862	Encke ... 1832
	4″·966	0·4445	92·338	Y. Villarceau 1849
	4″·800	0·4781	92·000	Mädler ... 1849
ζ Herculis, (3rd and 6·5th Mag.)	1″·208	0·4320	30·220	Mädler ... 1847
	1″·254	0·4482	36·357	Y. Villarceau 1847
η Coronæ, (5·5th and 6th Mag.)	0″·902	0·2891	42·500	Mädler ... 1847
	1″·012	0·4744	42·501	Y. Villarceau 1847
	1″·111	0·4695	66·257	The same, 2nd result.

The problem of the period of revolution of η Coronæ admits of two solutions: of 42·5 and 66·3 years; but the late observations of Otto Struve give the preference to the second. M. Yvon Villarceau finds the *semi-major axis*, *eccentricity*, and *period of revolution*, in years:

γ Virginis	3″·446	0·8699	153·787
ζ Cancri	0″·934	0·3662	58·590
α Centauri	12″·128	0·7187	78·486

The occultation of one *fixed star* by another, as was presented by ζ Herculis, I have called apparent (p. 287). M. Faye shows that it is a consequence of the spurious diameter of the stars (*Cosmos*, vol. iii. pp. 66 and 170,) seen in our telescopes. The parallax of 1830, Groombridge, which I gave (p. 27) as 0″·226, is found by Schlüter and Wichmann, 0″·182, and by Otto Struve, 0″·034.



VII.

NEBULOUS SPOTS.—ARE THESE ONLY REMOTE AND VERY DENSE CLUSTERS OF STARS?—THE TWO MAGELLANIC CLOUDS, IN WHICH CROWDED NEBULOUS SPOTS ARE INTERSPERSED WITH NUMEROUS STELLAR SWARMS.—THE SO-CALLED COAL-SACKS OF THE SOUTHERN HEMISPHERE.

AMONG the visible cosmical bodies occupying the regions of space, besides those which shine with *stellar light* (whether self-luminous, or illumined like planets, stars isolated or in multiple groups, and revolving round a common centre of gravity), there are also masses which present a *faint and milder nebulous light*.[1] These bodies, which appear at one time as sharply defined, disc-formed, luminous clouds, at another as irregularly and variously shaped masses, widely diffused over large spaces, seem to the naked eye, at first sight, to be wholly different from those cosmical bodies of which we treated fully in the last four sections of the Astrognosy. In the same way that there is an inclination to infer from the observed and as yet unexplained motion of the *visible* cosmical bodies[2] the existence of others hitherto *invisible*, so the knowledge gained as to the *resolvability* of a considerable number of nebulous spots has recently led to

[1] *Cosmos*, vol. i. pp. 69–73, 75 and 131; vol. ii. p. 710; vol. iii. pp. 44–49, 189, 208 and 220.

[2] *Cosmos*, vol. iii. pp. 252–254.

conclusions regarding the non-existence of all nebulæ, and indeed of all cosmical vapour generally. But whether these well-defined nebulous spots be a self-luminous vapoury matter, or remote, closely-thronged globular *clusters of stars*,* they must ever remain objects of vast importance in the knowledge of the structure of the universe and of the contents of space.

The number whose positions have been determined by right ascension and declination, exceeds 3,600. Some of the more irregularly diffused, measure eight lunar diameters. According to William Herschel's earlier estimate, made in 1811, these nebulous spots cover at least $\frac{1}{270}$th part of the whole visible firmament. As seen through colossal telescopes, the contemplation of these nebulous masses leads us into regions from whence a ray of light, according to an assumption not wholly improbable, requires millions of years to reach our earth, to distances for whose measurement the dimensions (the distances of Sirius, or the calculated distances of the binary stars in Cygnus and the Centaur) of our nearest stratum of fixed stars scarcely suffice. If these nebulous spots be elliptical or spherical sidereal groups, their very conglomeration calls to mind the idea of a mysterious play of gravitating forces by which they are governed. If they be vapoury masses, having one or more nebulous nuclei, the various degrees of their condensation suggest the possibility of a process of gradual star-formation from inglobate matter. No other cosmical structure—no other subject of this branch of astronomy more contemplative than measuring—is, in like degree, adapted to excite the imagination, not merely as a symbolic image of the infinitude of space, but because the investigations of the different conditions of *existing things*, and of their presumed connection

* *Cosmos*, vol. i. p. 62.

of sequence, promises to afford us an insight into the laws of *genetic development*.

The historical development of our knowledge of nebulous bodies teaches us that here, as in the progress of almost every other branch of physical science, the same opposite opinions, which still have numerous adherents, were maintained long since, although on weaker grounds. Since the general use of the telescope, we find that Galileo, Dominique Cassini, and the sagacious John Michell, regarded all nebulæ as remote clusters of stars; whilst Halley, Derham, Lacaille, Kant, and Lambert, maintained the existence of starless nebulous masses. Kepler (like Tycho Brahe before the invention of the telescope) was a zealous adherent of the theory of star-formation from cosmical vapour—from condensed conglobate celestial nebulous matter. He believed "*cœli materiam tenuissimam* (the vapour which shines with a mild stellar light in the Milky Way,) *in unum globum condensatam, stellam effingere,*" and grounded his opinion, not on the process of condensation operating in defined roundish nebulous spots, (for these were unknown to him,) but on the sudden appearance of new stars on the margin of the Galaxy.

If we take into account the number of objects discovered, the accuracy of their telescopic investigation, and the generalization of views, the history of nebulous spots, like that of double stars, may be said to begin with William Herschel, Until his time there were not more than 120 unresolved nebulæ in both hemispheres, whose positions were determined, including even the results of Messier's meritorious labours; and in 1786 the great astronomer of Slough published the first catalogue, containing 1000. I have already fully pointed out in an earlier portion of this work that the bodies named *nebulous stars* (νεφελοειδεῖς) by Hipparchus and Geminus in the *Catasterisms* of the pseudo-Eratosthenes

and in the *Almagest* of Ptolemy, are stellar clusters which appear to the naked eye with a nebulous lustre.[4] This designation, latinized *nebulosæ*, passed in the middle of the thirteenth century into the Alphonsine Tables, probably through the preponderating influence of the Jewish astronomer, Isaac Aben Sid Hassan, Chief Rabbi of the wealthy synagogue at Toledo. The Alphonsine Tables first appeared in print in 1483 at Venice.

The first notice of a remarkable aggregation of innumerable *true nebulous spots*, blended with stellar swarms, dating from the middle of the tenth century, is in the writings of an Arabian astronomer, Abdurahman Sufi, a native of the Persian Irak. The *White Ox*, which he saw shining with a milky light far below Canopus, was undoubtedly the larger Magellanic cloud, which with an apparent breadth of nearly twelve lunar diameters, extends over a portion of the heavens measuring forty-two square degrees. No mention is made by European travellers of this phenomenon until the beginning of the sixteenth century, although, 200 years earlier, the Normans had advanced as far along the Western coasts of Africa as Sierra Leone (8 30′ N. Lat.).[5] It might have been expected that a nebulous mass of such vast extent,

[4] *Cosmos*, vol. iii. pp. 121 and note, and 190 and note.

[5] Prior to the expedition of Alvaro Becerra. The Portuguese advanced beyond the equator in 1471. See Humboldt's *Examen critique de l'Hist. de la Géographie du Nouveau Continent*, tom. i. pp. 290–292. In eastern Africa the Lagides had availed themselves, for purposes of commerce, of the passage along the Indian Ocean, and, favoured by the south-west monsoon (Hippalus), had passed from Ocelis in the Straits of Bab-el-Mandeb to the Malabar emporium of Muziris and to Ceylon (*Cosmos*, vol. ii. p. 539, and note). Although the Magellanic Clouds must have been seen in all these voyages, we meet with no record of their appearance.

which was distinctly visible to the naked eye, would have attracted attention sooner.[6]

The first *isolated* nebula which was observed and recognized by the telescope as wholly starless and as an object of special nature was the nebula near ν Andromedæ, which, like that last mentioned, is also visible to the naked eye. Simon Marius (Mayer of Gunzenhausen, in Franconia), originally a musician, and subsequently Court mathematician of one of the Margraves of Colmbach, the same person who saw the satellites of Jupiter nine days earlier than Galileo,[7] has also the merit

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[6] Sir John Herschel, *Observations at the Cape*, § 132.

[7] *Op. cit.* pp. 357, 509 (note 43). Galileo, who endeavoured to refer the difference in the days of discovery (29th of December, 1609, and 7th of January, 1610,) to a difference in the calendar, maintained that he had seen the satellites of Jupiter one day earlier than Marius, and even allowed himself to be so far carried away by his indignation at "the falsehood of the heretical impostor of Gutzenhausen" ("*bugia del impostore eretico Guntzenhusano,*") as to declare his belief "that very probably the heretic, Simon Marius, never observed the Medicean planets," ("*che molto probabilmente il eretico, Simon Mario, non ha osservato giammai i Pianeti Medicei.*")—See *Opere di Galileo Galilei*, Padova, 1744, tom. ii. pp. 235–237; and Nelli, *Vita e Commercio letterario di Galilei*, 1793, vol. i. pp. 240–246. The "heretic" had nevertheless expressed himself very pacifically and modestly in reference to the extent of merit due to his discovery. "I simply affirm," says Simon Marius, in the preface to the *Mundus Jovialis*, "hæc sidera (Brandenburgica) a nullo mortalium mihi ulla ratione commonstrata, sed propria indagine sub ipsissimum fere tempus, vel aliquanto citius quo Galilæus in Italia ea primum vidit, a me in Germania adinventa et observata fuisse. Merito igitur Galilæo tribuitur et mane laus primæ inventionis horum siderum apud Italos. An autem inter meos Germanos quispiam ante me ea invenerit et viderit, hactenus intelligere non potui." "I simply affirm that I was

of having given the first, and indeed a very accurate description of a nebula. In the preface to his *Mundus Jovialis*,[8] he relates, that "on the 15th of December, 1612, he observed a fixed object differing in appearance from any he had ever seen. It was situated near the 3rd and northern star of Andromeda's girdle; seen with the naked eye, it appeared to him to be a a mere cloud, and by the aid of the telescope he could not discover any signs of a stellar nature, a circumstance which distinguished it from the nebulous stars in Cancer, and from other nebulous clusters. All that could be recognized was a whitish glimmering appearance, brighter in the centre, and fainter towards the margins. With a diameter of $\frac{1}{4}$ of a degree, the whole resembled a light seen from a great distance through half-transparent horn plates: (*similis fere splendor apparet, si a longinquo candela ardens per cornu pellucidum de noctu cernatur*)." Simon Marius hazards a conjecture whether this singular star be not of recent formation, but will not give a decided opinion, although it strikes him as singular that Tycho Brahe, who had enumerated all the stars in the girdle of Andromeda, should have said nothing of this *nebulosa*. The *Mundus Jovialis*, which first appeared in 1614, indicates, therefore, as I have already observed elsewhere,[9] the

led to the discovery of these stars not by any reasonings of others, but by the result of my own investigations, and that they were observed by me in Germany, about the very same time or a little sooner than Galileo first saw them in Italy. To Galileo, among the Italians, is therefore due the merit of having first discovered these stars. But whether, among my own countrymen in Germany, any person before me has discovered and seen them, I have not as yet been able to ascertain."

[8] *Mundus Jovialis, anno* 1609, *detectus ope perspicilli Belgici.* (Noribergæ, 1614.)

[9] *Cosmos*, vol. ii. p. 702.

difference between a nebulous spot unresolvable by the telescopic powers of that age, and a cluster of stars,* to which the mutual proximity of its numerous small stars, not visible to the naked eye, imparts a nebulous lustre. Notwithstanding the great improvements made in optical instruments, the nebula in Andromeda was considered for nearly two centuries and a half—as at its discovery—to be wholly devoid of stars, until two years since, the transatlantic observer, George Bond, of Cambridge in Massachusetts, discovered 1,500 small stars within the limits of the nebula. I have not hesitated to class it amongst the stellar clusters, although the nucleus has not hitherto been resolved.[10]

It is probably only to be ascribed to some singular accident that Galileo, who, when the *Sidereus Nuntius* appeared in 1610, had already made frequent observations of the constellation of Orion; should have subsequently mentioned, in his *Saggiatore*, no other nebulæ in the firmament but those which his own weak optical instruments had resolved into stellar clusters, although he might long before have learnt, through the *Mundus Jovialis* of the discovery of the starless nebula in Andromeda. When he speaks of the *nebulose del Orione e del Presepe*, he understands by the expression merely "aggregations (*coacervazioni*) of innumerable small stars."[11] He successively delineates under the deceptive designations of *nebulosæ capitis, cinguli, et ensis Orionis*, clusters of stars, in which he exults in having discovered 400 hitherto unobserved stars in a space of 1 or 2 degrees. He never makes any reference to *unresolved* nebulous matter. Yet how could

* *Germ.*, Sternhaufen; *French*, amas d'étoiles.

[10] *Cosmos*, vol. iii. p. 192.

[11] "*Galilei notò che le Nebulose di Orione null' altro erano che mucchi e coacervazioni d' innumerabili Stelle.*"—Nelli, *Vita di Galilei*, vol. i. p. 208.

the great nebulous spot in the sword of Orion have failed to rivet his attention? But although this great observer probably never saw the irregular nebula in Orion, or the roundish disc of a so-called irresolvable nebula, still his general views[18] on the intrinsic nature of nebulous spots were very similar to those

[18] "In primo integram Orionis Constellationem pingere decreveram; vero, ab ingenti stellarum copia, temporis vero inopia obrutus, aggressionem hanc in aliam occasionem distuli. Cum non tantum in Galaxia lacteus ille candor veluti albicantis nubis spectetur, sed *complures consimilis coloris areolæ sparsim per æthera subfulgeant*, si in illarum quamlibet specillum convertas, stellarum constipatarum cœtum offendes. Amplius (quod magis mirabile) stellæ, ab astronomis singulis in hanc usque diem *nebulosæ* appellatæ, stellarum mirum in modum consitarum greges sunt: ex quarum radiorum commixtione, dum unaquaque ob exilitatem, seu maximam a nobis remotionem, oculorum aciem fugit, candor ille consurgit, qui densior pars cœli, stellarum aut solis radios retorquere valens, hucusque creditus est."—*Opere di Galileo Galilei*, Padova, 1744, tom. ii. pp. 14, 15. "At first I had resolved to describe the whole constellation of Orion; but the multitude of the stars and the want of leisure compelled me to postpone the undertaking till another occasion. Since not only in the Milky Way may be observed that brilliancy as of a whitish cloud, but several areoles of a similar colour are scattered through the firmament; if you direct the glass to any one of them you will meet with a host of clustered stars. Moreover, the stars (still stranger to say) which, by every astronomer, are to this day called nebulous, are clusters of stars lying close together in a wonderful manner, from the combination of whose rays (while they cannot be separately distinguished by the eye on account of their minuteness, or their very great distance from us) arises that whiteness, which, from its capacity of reflecting the rays of the stars or of the sun, has been hitherto supposed to belong to a denser part of the atmosphere." *Sidereus Nuntius*, pp. 13, 15 (nos. 19–21), and 35 (no. 56).

to which the greater number of our astronomers of the present day incline. Like Galileo, Hevel of Dantzig, who, although a distinguished observer, was not much inclined to rely upon telescopic observation for aid in cataloguing the stars,[13] made no mention in his writings of the great nebula in Orion. His star catalogue, moreover, did not contain upwards of 16 nebulous spots, of which the positions were accurately determined.

At length, in the year 1656, Huygens discovered[14] the nebula in the sword of Orion, which is so important from its extent and form, and has become so famous from the number and celebrity of its subsequent investigators. Huygens was the means of inducing Picard (in 1676) to devote himself diligently to the investigation of this nebulous body. Edmund Halley, during his sojourn in St. Helena in 1677, was the first to determine any of the nebulous spots belonging to portions of the southern heavens not visible in Europe, although his observations embraced only a very small number. The lively interest taken by the great Cassini (Jean Dominique) in all branches of contemplative astronomy, led him, towards the close of the seventeenth century, to a more careful exploration of the nebulæ in Andromeda and Orion. He thought he could detect alterations in the latter since Huygens' observations, and that he "had recognized stars in the former

[13] Compare *Cosmos*, vol. iii. p. 51. I also remember a vignette at the close of the introduction to Hevel's *Firmamentum Sobescianum*, 1687, in which three genii are represented, two of whom are making observations with Hevel's sextants. The third genius is carrying a telescope which he appears to be offering, while those observing, exclaim, *Præstat nudo oculo!*

[14] Huygens, *Systema Saturnium*, in his *Opera varia*, Lugd. Bat. 1724, tom. ii. pp. 523 and 593.

which could not be seen with telescopes of low powers." There are reasons for regarding the assertion of an alteration of figure as a delusion; not entirely so the existence of stars in the nebula in Andromeda since the remarkable observations of George Bond. Cassini, moreover, conjectured, on theoretical grounds, the possibility of such a resolution of the nebula; since, in direct opposition to Halley and Derham, he considered all nebulous spots to be very remote stellar swarms.[15] The faint mild effulgence in Andromeda was indeed according to his opinion analogous to the zodiacal light, which he also conjectured to be composed of a crowd of densely thronged small planetary bodies.[16] Lacaille's residence in the southern hemisphere (at the Cape of Good Hope, and in the Isle of France and Bourbon, between 1750–1752), so considerably increased the number of known nebulous spots, that Struve has justly remarked, that from the observations of this traveller more was known at that time of the nebulous bodies of the southern hemisphere, than of those which were visible in Europe. Lacaille, moreover, successfully attempted to divide nebulæ into classes according to their apparent con-

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[15] "*Dans les deux nébuleuses* d'Andromede et d'Orion, j'ai vu des étoiles qu'on n'aperçoit pas avec des lunettes communes. Nous ne savons pas si l'on ne pourrait pas avoir des lunettes assez grandes pour que toute la nébulosité pût se résoudre en de plus petites étoiles, comme il arrive à celle du Cancer et du Sagittaire." "I have seen stars in the nebulæ of Andromeda and Orion," says Dominique Cassini, "which cannot be recognized by ordinary instruments. We are ignorant whether telescopes may not be constructed of sufficient power to resolve the whole nebula into smaller stars, as has been done in the case of the nebulæ in Cancer and Sagittarius."—Delambre, *Hist. de l'Astr. moderne*, tom. ii. pp. 700 and 744.

[16] *Cosmos*, vol. i. p. 130, note.

figuration; he also was the first to undertake, though with little result, the difficult task of analysing the heterogeneous contents of the Magellanic Clouds (*nubecula major et minor*). If we subtract the 14 nebulæ; which, even with instruments of low powers, were perfectly resolved into true clusters of stars, from the other 42 isolated nebulous spots which La-Caille observed in the southern heavens, there remain only 28, whilst Sir John Herschel, by the aid of more powerful instruments, as well as greater skill and superior powers of observation, succeeded in discovering under the same zone, and also independently of clusters, as many as 1,500 nebulous spots.

Devoid of personal knowledge or experience of the subject, and originally ignorant of each other's attempts, although both had very similar aims in view,[17] Lambert (from 1749) and Kant (from 1755) speculated with admirable sagacity on nebulous spots, detached galaxies and sporadic nebulous and stellar islands scattered singly through the realms of space. Both inclined to the nebular hypothesis, and to the idea of a perpetual development in the regions of space, and even of a star-formation from cosmical vapour. The great traveller, Le Gentil (1760–1769), long before his voyages, and his unsuccessful observations of the transit of Venus, had imparted animation to the study of nebulæ by his

[17] On the community and difference of ideas between Kant and Lambert, as well as in reference to the period of their publications, see Struve, *Etudes d'Astr. stellaire*, pp. 11, 13, 21, notes 7, 15, and 33. Kant's *Allgemeine Natur-Geschichte und Theorie des Himmels* appeared anonymously, and was dedicated to Frederick the Great, 1755. Lambert's *Photometria*, as already remarked, appeared in 1760; and his *Sammlung kosmologischer Briefe über die Einrichtung des Weltbaues*, in 1761.

observations on the constellations of Andromeda, Sagittarius, and Orion. He made use of an object-glass of Campani's, 37 feet in focal length, which was in the possession of the Paris Observatory. In entire opposition to the views of Halley, Lacaille, Kant, and Lambert, the intellectual John Michell declared (as Galileo and Dominique Cassini had done) that all nebulæ were stellar clusters, aggregations of very minute or very remote telescopic stars, whose existence would undoubtedly be some day revealed by means of more perfect optical instruments.[18] Compared with the slow progress we have hitherto depicted, the knowledge of nebulous spots received a rich accession of facts by the persevering industry of Messier. His catalogue of 1771 contains, after deducting the older nebulæ discovered by Lacaille and Méchain, 66 which had not been previously observed. He had the merit of doubling the number of the nebulous spots hitherto enumerated in both hemispheres, although his labours were carried on in the ill-supplied Observatoire de la Marine (Hôtel de Clugny).[19]

To these feeble beginnings succeeded the brilliant epochs of the discoveries of William Herschel and his son. The former began as early as 1779 a regular exploration of the numerous nebulous masses with which the heavens are studded. These observations were made with a seven-feet reflector. His colossal forty-feet telescope was completed in 1787; and in

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[18] "Those nebulæ," says John Michell in 1767, (*Philos. Transact.* vol. lvii. for 1767, p. 251,) "in which we can discover either none, or only a few stars, even with the assistance of the best telescopes, are probably systems that are still more distant than the rest."

[19] Messier, in the *Mém. de l'Académie des Sciences*, 1771, p. 435, and in the *Connaissance des Temps pour* 1783 *et* 1784. The whole catalogue contains 103 objects.

the three catalogues[20] which he published in 1786, 1789, and 1802, he indicated the positions of 2,500 nebulæ and clusters of stars. Until 1785, or almost as late as 1791, this great observer appears to have been more disposed, like Michell, Cassini, and the present Lord Rosse, to regard the nebulous spots which he was unable to resolve, as very remote clusters of stars; but a prolonged consideration of the subject between 1799 and 1802, led him to adopt the nebular theory, as Halley and Lacaille had done, and even, with Tycho Brahe and Kepler, the theory of a star-formation through the gradual condensation of cosmical vapour. The two hypotheses, however, are not necessarily connected.[21] The nebulous and stellar clusters observed by Sir William Herschel, were subjected by his son to a renewed investigation from 1825 to 1833; he also enriched the older catalogues with 500 new objects, and published in the *Philosophical Transactions for* 1833, (pp. 365–481,) a complete catalogue of 2,307 nebulæ and clusters of stars. This great work contains all that had been discovered in the heavens of Central Europe; and in the five succeeding years (from 1834–1838) we find Sir John Herschel engaged at the Cape of Good Hope in exploring the whole of the visible firmament with a colossal twenty-feet reflector, and adding 1,708 determinations of position to his previous catalogue of 2,307 nebulæ and clusters of stars![22] Only one-

[20] *Philos. Transact.* vols. lxxvi. lxxix. and xcii.

[21] "The nebular hypothesis, as it has been termed, and the theory of sidereal aggregation, stand in fact quite independent of each other."—Sir John Herschel, *Outlines of Astronomy*, § 872, p. 599.

[22] The numbers which I here give include the objects enumerated from Nos. 1 to 2,307 in the European, *Northern* Catalogue of 1833, and those from Nos. 2,308 to 4,015 in the African, *Southern* Catalogue.—*Observations at the Cape* pp. 51–128.

third of the southern nebulæ and clusters of stars in Dunlop's catalogue (containing 629 nebulous bodies, observed from 1825–1827, at Paramatta, with a nine-feet reflector, having a nine-inch speculum[23],) were inserted in Sir John Herschel's work.

A third great epoch in our knowledge of these mysterious cosmical bodies commenced with the construction of the marvellous fifty-three feet telescope[24] of the Earl of Rosse, at Parsonstown. All that had ever been advanced on either side of the question, during the long fluctuation of opinions in the different stages of the development of cosmical contemplation, was now made the subject of keen discussion in the contest regarding the nebular hypothesis and its asserted untenability. It appears from all the notices I have been able to collect from the works of distinguished astronomers long accustomed to the observation of nebulous spots, that out of a large number of nebulæ indiscriminately taken from among all the classes contained in the catalogue of 1833, and regarded as irresolvable, almost all (Dr. Robinson, the Director of the Armagh Observatory, enumerates more than 40 such,) have been perfectly resolved.[25] Sir John Herschel

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[23] James Dunlop, in the *Philos. Transact.* for 1828, pp. 113–151.

[24] Compare *Cosmos*, vol. iii. p. 85 and note.

[25] See *An Account of the Earl of Rosse's great Telescope*, pp. 14–17, which gives a list of the nebulæ resolved by Dr. Robinson and Sir James South in March, 1845. "Dr. Robinson could not leave this part of his subject without calling attention to the fact, that no real nebula seemed to exist among so many of these objects chosen without any bias: all *appeared* to be clusters of stars, and every additional one which shall be resolved will be an additional argument against the existence of any such."—Schumacher, *Astr. Nachr.* no. 536. In the *Notice*

maintains the same view, as well in his opening address before the British Association at Cambridge in 1845, as in the *Outlines of Astronomy*, 1849, where he expresses himself as follows:—"The magnificent reflecting telescope constructed by Lord Rosse, six feet in aperture, has resolved or rendered resolvable multitudes of nebulæ which had resisted all inferior powers. . . . Although, therefore, nebulæ do exist which, even in this powerful telescope, appear *as* nebulæ, without any sign of resolution, it may very reasonably be doubted whether there be really any essential physical distinction between nebulæ and clusters of stars."[38]

sur les grands Télescopes de Lord Oxmantown, aujourd'hui Earl of Rosse (*Bibliothèque universelle de Genève*, tom. lvii. 1845, pp. 342–357), we find the following passage: "Sir James South rappelle que jamais il n'a vu de représentations sidériales aussi magnifiques que celles que lui offrait l'instrument de Parsonstown; qu'une bonne partie des nébuleuses se presentaient comme des amas ou groupes d'étoiles, tandis que quelques autres, à ses yeux du moins, n'offraient aucune apparence de résolution en étoiles." "Sir James South remarks that he never beheld more magnificent representations of the stars than those he saw in the Parsonstown telescope, and that a great number of nebulæ appeared like clusters or groups of stars, whilst others, at least to his sight, presented no appearance of resolution."

[38] See *Outlines*, pp. 597, 598; also the *Report of the Fifteenth Meeting of the British Association held at Cambridge in June*, 1845, p. xxxvi.:—"By far the major part," says Sir John Herschel, "probably, at least, nine-tenths, of the nebulous contents of the heavens consist of nebulæ of spherical or elliptical forms, presenting every variety of elongation and central condensation. Of these a *great number* have been resolved into distant stars (by the reflector of the Earl of Rosse) and a vast multitude more have been found to present that mottled appearance which renders it almost a matter of certainty that an increase of optical power would show them

The constructor of the powerful optical apparatus at Parsonstown, who always discriminates between the result of actual observation and the promises of a knowledge to which we hope to attain, expresses himself with much caution regarding the nebula in Orion, in a letter to Professor Nichol of Glasgow,[27] dated Parsonstown, 19th March, 1846: —"In accordance with my promise of communicating to you the result of our examination of Orion, I think I may safely say, that there can be little, if any, doubt of the resolvability of the nebula. Since you left us, there was not a single night when, in absence of the moon, the air was fine enough to admit of our using more than half the magnifying power the speculum bears; still we could plainly see that all about the trapezium is a mass of stars, the rest of the nebulæ also abounding with stars, and exhibiting the characteristics of resolvability strongly marked." At a subsequent period (1848) Lord Rosse had not announced that his expectations had as yet been fulfilled, although he cherished the hope of being able to resolve the remaining portion of the nebula into stars.

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to be similarly composed. A not unnatural or unfair induction would, therefore, seem to be, that those which resist such resolution do so only in consequence of the smallness and closeness of the stars of which they consist; that, in short, they are only optically and not physically nebulous. Although nebulæ do exist which, even in this powerful telescope (of Lord Rosse) appear as nebulæ, without any sign of resolution, it may very reasonably be doubted whether there be really any essential physical distinction between nebulæ and clusters of stars."

[27] Dr. Nichol, Professor of Astronomy at Glasgow, published the letter above referred to in his *Thoughts of some Important Points relating to the System of the World*, 1846, p. 55.

When we separate the results of actual observation from those of mere inductive conclusions, in this much disputed question of the existence or non-existence of a self-luminous, vaporous matter in the universe, we find that although the increasing improvements in telescopic vision may, indeed, considerably diminish the number of nebulæ, they cannot by any means wholly exhaust them. By the application of increasing powers, each new instrument may resolve what the preceding ones had left unresolved, but it must at the same time, in consequence of its greater powers of penetrating space, replace (at least partially) the resolved nebulæ by others not previously reached.[28] A resolution of the older, and the discovery of new nebulæ, would therefore follow one another in endless succession, as the fruit of increased optical power. For if we suppose a different result, we must either, according to my view, assume the occupied regions of space to be limited, or that the world-islands, to one of which our system belongs, are so remote from each other that no telescopic instrument can ever be invented of sufficient power to penetrate to the confines of any other of these worlds, and that our last or extremest nebulæ may resolve themselves into clusters of stars, which, like the stars in the Milky Way, "are projected on a black ground entirely free from vapour."[29] But can we believe in the probability of a condition of the universe, and of a degree of perfection in optical instruments, in which the entire firmament will no longer exhibit any unresolved nebulous spots?

The hypothetical assumption of a self-luminous fluid, appearing, when sharply-defined, in round or oval nebulous spots, must not be confounded with the equally hypothetical assump-

[28] Compare *Edinburgh Review*, vol. lxxxvii. 1848, p. 186.
[29] *Cosmos*, vol. iii. p. 195, and note.

tion of a non-luminous ether pervading the universe, and generating by its undulatory motion, the phenomena of light, radiant heat, and electro-magnetism.[30] The emanations from cometary nuclei, which in the form of tails frequently extend over enormous tracts of space, disperse the substance of which they are composed—and with which we are unacquainted,—among the planetary orbits of our solar system, which they intersect. But when separated from the controlling nucleus, this substance ceases to be perceptibly luminous. Newton even considered it possible that *vapores ex sole et stellis fixis et caudis cometarum*, "vapours from the sun, the stars, and the tails of comets," might blend with our terrestrial atmosphere.[31] No telescope has as yet indicated any sidereal character in the vaporous, rotating, and flattened ring of the zodiacal light. Whether the particles of which this ring consists, and which according to some are conceived to rotate upon themselves in obedience to dynamic conditions, and according to others merely to revolve round the Sun, are illumined or self-luminous, like many kinds of terrestrial vapours,[32] is a question as yet undecided. Dominique Cassini believed them to be small planetary bodies.[33] It seems as if it were a requirement of the human intellect to seek in all fluid bodies for discrete, molecular particles,[34] similar to the full or hollow vesicles of which clouds are formed; while the gradations in the decrease of density in our planetary system, from Mercury to Saturn and Neptune (from 1·12 to 0·14; the Earth being =1), leads the mind to the consideration of comets, through the external

[30] *Cosmos*, vol. iii. p. 40.

[31] Newton, *Philos. Nat. Principia Mathematica*, 1760, tom. iii. p. 671.

[32] *Cosmos*, vol. i. p. 131.

[33] *Ib.* p. 130.

[34] *Observations at the Cape*, § 109–111.

layers of whose nuclei even a faint star continues visible, and finally to that of discrete particles, so deficient in density that their solidity, either within large or small dimensions, can scarcely be characterized, except by the limits which bound them. It was by such considerations as to the constitution of the apparently vaporous zodiacal light that Cassini, long before the discovery of the so-called smaller planets between Mars and Jupiter, and prior to all conjectures regarding meteor-asteroids, was led to the idea that there exist cosmical bodies of all dimensions and all degrees of density. We here almost involuntarily touch upon the old metaphysical controversy regarding matter of primitive fluidity and that composed of discrete molecular particles, and therefore more amenable to mathematical treatment. From hence we turn the more readily to our former consideration of the purely objective part of the phenomenon.

In the 3,926 (2,451 + 1,475) positions which belong—*a*. to the portion of the firmament visible at Slough, and which we shall here for the sake of brevity term the *northern* heavens, according to the three catalogues of Sir William Herschel from 1786 to 1802, and the above-named great exploration of the heavens published by his son in the *Philos. Transact.* of 1833; and *b*. to the portion of the *southern* heavens visible at the Cape of Good Hope, according to Sir John Herschel's African Catalogues,—nebulæ and clusters of stars are set down indiscriminately together. I have, however, deemed it best, notwithstanding the natural affinity of these objects, to enumerate them separately, in order to indicate a definite epoch in the history of their discovery. I find that the *Northern* Catalogue[35] contains 2,299 nebulæ and

[35] The data on which these numbers are based require some explanation. The three catalogues of the elder Herschel

152 clusters of stars; the *Southern* or Cape Catalogue, 1,239 nebulæ and 236 clusters of stars. We have, therefore, 3,538 for the number of the nebulæ throughout the firmament which were given in these catalogues, as not yet resolved

contain 2,500 objects, viz. 2,303 nebulæ and 197 clusters of stars. (Mädler, *Astr.* p. 448.) These numbers were altered in the subsequent and far more exact exploration made by Sir John Herschel (Observations of Nebulæ and Clusters of Stars made at Slough with a twenty-feet reflector, between the years 1825 and 1833, in the *Philosophical Transactions of the Royal Society of London for the year* 1833, pp. 365–481). About 1,800 objects were identical with those of the three earlier catalogues: but 300 or 400 were temporarily excluded, and more than 500 newly discovered were determined according to Right Ascension and Declination. (Struve, *Astr. Stellaire,* p. 48.) The *Northern* Catalogue contains 152 clusters of stars, consequently 2,307—152=2.155 nebulæ; but in reference to the *Southern* Catalogue (*Observations at the Cape,* p. 3, § 6, 7.) we have to subtract from the 4,015—2,307 =1,708 objects, among which there are 236 clusters of stars (see *Op. cit.* p. 3, § 6, 7, p. 128), 233, viz. 89+135+9, as belonging to the Northern Catalogue, and observed by Sir William and Sir John Herschel at Slough, and by Messier in Paris. There remain, therefore, for the Cape observations, 1,708—233=1,475 nebulæ and clusters of stars, or 1,239 nebulæ alone. We have, however, to add 135+9=144 to the 2,307 objects of the Northern Slough Catalogue, which increase its numbers to 2,451 objects, in which, after subtracting 152 clusters, there remain 2,299 nebulæ, a number which is not, however, very strictly limited to the latitude of Slough. When numerical relations are to be given in the topography of the firmament of both hemispheres, the author feels that although such data are from their nature variable, owing to the differences in the epochs and the advances of observation, he is bound to have regard to their accuracy. In a sketch of the Cosmos, it must be endeavoured to delineate the condition of science appertaining to a definite epoch.

into clusters. This number may, perhaps, be increased to 4,000, if we take into account 300 or 400 seen by Sir William Herschel,[36] but not again determined, and the 629 observed by Dunlop at Paramatta, with a nine-inch Newtonian reflector, of which Sir John Herschel included only 206 in his catalogue.[37] Similar results have recently been published by Bond and Mädler. The number of nebulæ, compared with that of double stars appears, therefore, according to the present condition of science, to be in the ratio of 2 : 3; although it must not be forgotten that under the designation of double-stars are included those which are merely *optically* double, and that hitherto alterations of position have only been observed in a ninth, or perhaps but an eighth portion of the whole number.[38]

The above numbers—2,299 nebulæ, with 152 clusters of stars, in the Northern, and only 1,239 nebulæ, with 236 clusters of stars, in the Southern Catalogue,—show that the southern hemisphere, with a smaller number of nebulæ, possesses a preponderance of *clusters of stars.* If we assume that all nebulæ are from their probable constitution resolvable, as merely more remote clusters of stars or stellar groups, composed of smaller and less thronged, self-luminous celestial bodies, this apparent contrast (whose importance has been the more noticed by Sir John Herschel[39] in consequence of

[36] Sir John Herschel says, in his *Observations at the Cape*, p. 134, "There are between 300 and 400 nebulæ of Sir William Herschel's Catalogue still unobserved by me; for the most part very faint objects."

[37] *Op. cit.* § 7. Compare Dunlop's *Cat. of Nebulæ and Clusters of the Southern Hemisphere,* in the *Philos. Transact.* for 1828, pp. 114–146.

[38] *Cosmos*, vol. iii. p. 272.

[39] *Observations at the Cape*, § 105–107.

his having employed reflectors of equal powers in both hemispheres), indicates, at least, a striking difference in the nature and cosmical position of nebulæ, that is to say, in reference to the directions in which they present themselves to the observation of the inhabitants of the earth in the northern or southern firmament.

We owe to the same great observer our first accurate knowledge of, and cosmical survey of the distribution of nebulæ and groups of stars throughout the entire heavens. With a view of investigating their position, relative local accumulation, and the probability or improbability of their being arranged in accordance with certain characteristic features, he classified between three and four thousand objects graphically, in divisions, each embracing a space measuring 3° Declination and 15m. Right Ascension. The greatest accumulation of nebulous spots occurs in the northern hemisphere, where they are distributed through Leo Major and Leo Minor; the body, tail, and hind feet of the Great Bear; the nose of Camelopardalus; the tail of the Dragon; Canes Venatici; Coma Berenices (where the north pole of the galaxy is situated);[40] the right foot of Böotes; and more especially through the head, wings, and shoulder of Virgo. This zone, which has been termed the nebulous region of Virgo, contains, as already stated,[41] one-third of all the nebulous bodies in a space embracing the eighth part of the surface of the celestial hemisphere. It does not stretch far beyond the

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[40] In the *Cosmos*, vol. iii. p. 194, lines 5 and 6 from the top, by an error of the press the words *south pole* and *north pole* have been confounded.

[41] "In this *region of Virgo*, occupying about one-eighth of the whole surface of the sphere, one-third of the entire nebulous contents of the heavens are congregated."—*Outlines*, p. 596.

ecliptic, extending only from the southern wing of Virgo to the extremity of Hydra and to the head of the Centaur, without reaching its feet or the Southern Cross. A less dense accumulation of nebulæ in the northern hemisphere, which extends further south than the former, has been named by Sir John Herschel *the nebulous region of Pisces.* It forms a zone, beginning with Andromeda, which it almost entirely incloses, stretching beyond the breast and wings of Pegasus, and the band uniting the Fishes, and extending towards the southern galactic pole and Fomalhaut. A striking contrast to these accumulations presents itself in the barren region lying near Perseus, Aries, Taurus, the head and chest of Orion, around Auriga, Hercules, Aquila, and the whole constellation of Lyra.* If we divide all the nebulæ and clusters of stars contained in the Northern Catalogue (of Slough), and classified according to Right Ascension (as given in Sir John Herschel's *Observations at the Cape.*) into six groups of four hours each, we obtain the following result:—

R. Asc.	0h.	..	4h.	311
	4	..	8	179
	8	..	12	606
	12	..	16	850
	16	..	20	121
	20	..	0	239

By a more careful separation, according to Northern and Southern Declination, we find that in the six hours Right Ascension from 9h.—15h. there are accumulated 1,111 nebulæ

* In reference to this barren region, see *Observations at the Cape,* § 101, p. 135.

and clusters of stars in the northern hemisphere alone, viz.:[43]

From	9h. ..	10h.	90
	10 ..	11	150
	11 ..	12	251
	12 ..	13	309
	13 ..	14	181
	14 ..	15	130.

The actual northern maximum lies, therefore, between 12h. and 13h., very near the north galactic pole. Beyond that point, between 15h. and 16h. towards Hercules, the diminution is so rapid that the number 130 is followed directly by 40.

The southern hemisphere presents not only a smaller number, but a far more regular distribution of nebulæ. Regions destitute of nebulæ here frequently alternate with sporadic nebulæ. An actual local accumulation, more dense indeed than the nebulous region of Virgo in the northern heavens, occurs only in the Great Magellanic Cloud, which alone contains as many as 300 nebulæ. The immediate polar regions of both hemispheres are poor in nebulæ, and to a distance of 15° the Southern Pole is still more so than the Northern, in the ratio of 4 to 7. The present North Pole exhibits a small nebula, only 5 minutes' distance from it, whilst a similar nebulous body, which Sir John Herschel has aptly named *Nebula polarissima Australis*, (No. 3176 of his *Cape Catalogue*, R. A. 9h. 27m. 56s.; N. P. D. 179° 34′ 14″) is situated at a distance of 25 minutes from the South Pole.

[43] I have based these numerical data on a computation of the numbers yielded by the projection of the northern heavens as given in *Observations at the Cape*, pl. xi.

This paucity of stars in the south polar region, and the absence of any pole-star visible to the naked eye, were made the subject of bitter lamentation by Amerigo Vespucci and Vicente Yañez Pinzon, when, at the close of the fifteenth century, they penetrated far beyond the equator to Cape San Augustin, and when the former even expressed the erroneous opinion that the fine passage of Dante, "*Io mi volsi a man destra, e posi mente . . .*" and the four stars described as "*non viste mai fuorch' alla prima gente,*" referred to antarctic polar stars.[44]

[44] Humboldt, *Examen critique de l'Hist. de la Géographie*, tom. iv. p. 319. The Venetian Cadamosto (more properly called Alvise da Ca da Mosto) first turned his attention to the discovery of the position of a south-polar star, when in company with Antoniotto Usodimare at the mouth of the Senegal, in 1454, in the course of one of the many voyages in which the Portuguese engaged, under the auspices of the Infante Don Henrique, for the purpose of advancing along the western shores of Africa, beyond the equator. "While I still see the north polar star," he writes, being then in about 13° north latitude, "I cannot see the south polar star itself, but the constellation which I perceive towards the south, is the *Carro del ostro*, (waggon of the south); (*Aloysii Cadam. Navig.*, cap. 43, p. 32; Ramusio, *Delle Navigationi et Viaggi*, vol. i. p. 107). Could he have traced the figure of a waggon among some of the larger stars of the constellation Argo? The idea that both poles had a constellation of the "Wain" or waggon, appears to have been so universal in that age that there is a drawing of a constellation perfectly similar to Ursa Minor, supposed to have been seen by Cadamosto, both in the *Itinerarium Portugallense*, 1508, fol. 23 *b*, and in Grynæus, (*Novus Orbis*, 1532, p. 58); whilst Ramusio (*Navigationi*, vol. i. p. 107), and the new *Collecção de Noticias para a Hist. e Geog. das Nações Ultramarinas* (tom. ii. Lisboa, 1812, p. 57, cap. 39), in the place of the former, give an equally arbitrary drawing of the Southern Cross. (Humboldt, *Examen crit. de l'Hist. de la Géogr.* tom. v. p. 236.)

We have hitherto considered nebulæ in reference to their number and their distribution in what we call the firmament, —an* apparent distribution which must not, however, be

Since, in the middle ages, and probably for the sake of replacing the two Dancers, χορευταί, of Hyginus (*Poet. Astron.* iii. 1), *i. e.* the *Ludentes* of the Scholiast of Germanicus, or the *Custodes* of Vegetius in the Lesser Wain, the stars β and γ of Ursa Minor had been denominated the Guards, *le due guardie*, of the neighbouring north pole, on account of their rotation round that point, and as this designation, as well as the habit of determining polar altitudes by these Guards (Pedro de Medina, *Arte de Navegar*, 1545, lib. v. caps. 4–7, pp. 183–195,) was familiar to the European pilots of all nations in the northern seas; so erroneous conclusions led men to believe from analogy that they could recognize in the southern horizon the polar star which had so long been sought for. It was not until Amerigo Vespucci's second voyage (from May, 1499, to September, 1500), when he and Vicente Yañez Pinzon (both voyages are perhaps one and the same) advanced as far in the southern hemisphere as Cape San Augustin, that they devoted themselves diligently, but to no purpose, to the search for a visible star in the immediate vicinity of the South Pole. (Baudini, *Vita e Lettere di Amerigo Vespucci*, 1745, p. 70; Anghiera, *Oceanica*, 1510, dec. i. lib. ix. p. 96; Humboldt, *Examen crit.* tom. iv. pp. 205, 319, 325.) The South Pole was then situated within the constellation Octans, so that β of Hydrus, if we follow the reduction of Brisbane's Catalogue, had still a southern declination of fully 80° 5′. "While I was engaged in observing the wonders of the southern heavens, and in vainly seeking for a pole-star, I was reminded," says Vespucci, in his letter to Pietro Francesco de' Medici, "of an expression made use of by our Dante, when, in the first chapter of the *Purgatorio*, he depicts a presumed passage from one hemisphere to the other, and in describing the Antartic Pole, says, *Io mi volsi a man destra* . . . . . . In my opinion the author intended in these verses to indicate the pole of the other firmament by his four stars (*non viste mai fuorch' alla*

confounded with their actual distribution through the regions of space. We now, therefore, proceed to the consideration of the remarkable differences presented by their individual

prima gente). I am the more certain of this, because I actually saw four stars, which together formed a lozenge, and had a slight (?) movement." Vespucci refers to the Southern Cross, *la croce maravigliosa* of Andrea Corsali (Letter from Cochin, dated January 6, 1515, in *Ramusio*, vol. i. p. 177), whose name he did not then know; but which, subsequently served to mark to all pilots the position of the South Pole (as β and γ Urs. Min. indicated the North Pole. (*Mém. de l'Acad. des Sciences*, 1666–1699, tom. vii. part 2. Paris, 1729, p. 58.) This constellation also served for determinations of latitude. (Pedro de Medina, *Arte de Navegar*, 1545, lib. v. cap. xi. p. 204.) Compare my investigation of the celebrated passage of Dante in the *Examen crit. de l'Hist. de la Géogr.* tom. iv. pp. 319–334. I there drew attention to the fact that α of the Southern Cross, which was carefully observed in modern times, by Dunlop (1826), and by Rümker (1836), at Paramatta, is one of those stars whose multiple nature was first recognized in 1681 and 1687 by the Jesuits Fontaney, Noël, and Richaud. (*Hist. de l'Acad. dep.* 1686–1699, tom. ii. Par. 1733, p. 19; *Mém. de l'Acad. dep.* 1666–1699, tom. vii. 2, Par. 1729, p. 206; *Lettres édifiantes*, recueil vii. 1703, p. 79.) This early recognition of binary systems, long before that of ζ Ursæ Maj. (*Cosmos*, vol. iii. p. 252), is the more remarkable, as Lacaille, seventy years later, did not describe α Crucis as a double star; perhaps (as Rümker conjectures), because the main star and the companion were then not sufficiently distant from each other. (Compare Sir John Herschel, *Observations at the Cape*, § 183–185.) Richaud also discovered the binary character of α Centauri, almost simultaneously with that of α Crucis, and fully nineteen years before the voyage of Feuillée, to whom Henderson erroneously attributed the discovery. Richaud remarks, "that at the time of the Comet of 1689, the two stars which form the double star α Crucis were at a considerable distance from each other; but that in a twelve-feet refractor, both parts of α Centauri

forms, which are either regular (globular, more or less elliptical, annular, planetary, or resembling the photosphere surrounding a star), or irregular and almost as difficult to classify as those of the aggregated aqueous vapour of our atmosphere—the clouds. The elliptical (spheroidal) form[45] has been regarded as the normal type of nebulæ; this form is most readily resolved into clusters of stars, when it assumes a globular shape in the telescope; but when, on the other hand, with instruments of equal powers, it appears much flattened, elongated in one dimension, and discoidal, it is less easy of resolution.[46] Gradual transitions of form from the round to the elongated, elliptical, or awl-shaped form, are of frequent occurrence in the heavens. (*Philos. Transact.* 1833, p. 494, pl. ix. figs. 19–24.) The nebula is always condensed around one or more central points (nuclei). It is only among the class of round and oval *nebulæ* that we recognize *double nebulæ*, in which, as no relative motion is perceptible among the individual nebulous bodies, either in consequence of its absence or its extreme slowness, we are deficient in a

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could be distinctly recognized, and appeared to be nearly in contact."

[45] *Observations at the Cape*, § 44, 104.

[46] *Cosmos*, vol. iii. p. 190 and note. As we have already remarked in reference to clusters of stars (*Ibid.*, p. 193), Mr. Bond, of the United States, succeeded, by means of the great space-penetrating power of his refractor, in completely resolving the very elongated, elliptical nebula of Andromeda, which, according to Bouillaud, had been already described before the time of Simon Marius in 985 and 1428. It has a reddish light. Near this celebrated nebula lies the still unresolved, but very similarly shaped nebula, discovered on the 27th of August, 1783, by my honoured friend, Miss Caroline Herschel, who died at an advanced age, universally esteemed. (*Philos. Transact.* 1833, No. 61 of the Catalogue of Nebulæ, fig. 52.)

criterion by which to prove the existence of a mutual relation between the two, as in distinguishing between *physically*, and merely *optically* double stars. Figures of double nebulæ are given in the *Philos. Transact.* for the year 1833, figs. 68–71. Compare also Herschel, *Outlines of Astr.* § 878; *Observ. at the Cape of Good Hope*, § 120.

Annular nebulæ are of the rarest occurrence. According to Lord Rosse, we are acquainted with seven of these bodies in the northern hemisphere; the most celebrated of these is situated between β and γ Lyræ (No. 57, Messier; No. 3023 of Sir John Herschel's Catalogue), and was discovered in 1779 by Darquier at Toulouse, when Bode's Comet passed near it. Its apparent size is nearly equal to that of Jupiter's disc, and its form is an ellipse, whose greater and lesser axes are in the ratio of 5 to 4. The interior of the ring is not black, but somewhat illumined. Sir William Herschel discovered some stars in the ring, which has since been entirely resolved by Lord Rosse and Mr. Bond.[47] The splendid annular nebulæ of the southern hemisphere, numbered 3680 and 3686, appear, on the contrary, perfectly black in the interior of the rings. The last-named of the two is not elliptical, but perfectly round;[48] all are probably annular clusters of stars. The increasing power of optical instruments appears, moreover, generally to render the contour of both elliptical and annular nebulæ less defined; thus, for instance, Lord

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[47] "*Annular Nebulæ*:"—*Observations at the Cape*, p. 53; *Outlines of Astr.* p. 602. "*Nébuleuse perforée*:"—Arago, in the *Annuaire pour* 1842, p. 423; Bond, in Schum. *Astron. Nachr.* No. 611.

[48] *Observations at the Cape*, p. 114, pl. vi. figs. 3 and 4. Compare also No. 2072 in the *Philos. Transact.* for 1833, p. 466. See Nichol, *Thoughts on the System of the World*, p. 21, pl. iv. and p. 22, pl. i. fig. 5.

Rosse's colossal telescope exhibits the annular nebula of Lyra in the form of a simple ellipse, with remarkable divergent, thread-like nebulous appendages. The transformation effected in a nebulous spot—Lord Rosse's *Crab nebula*—which appears in instruments of inferior power to be a simple elliptical body, is particularly striking.

The so-called planetary nebulæ, which were first observed by the elder Herschel, and which rank amongst the most remarkable phenomena of the heavens, although of less rare occurrence than annular nebulæ, do not number, according to Sir John Herschel, more than 25, of which nearly three-fourths lie within the southern hemisphere. These bodies present the most striking resemblance to planetary discs; the greater number are round, or somewhat oval, and either sharply defined or indistinct and vaporous at the margins. The discs of many of these nebulæ present a very uniform light, whilst others appear mottled, or of a peculiar texture as if curdled. No trace of condensation round a central point has ever been observed. Lord Rosse has recognized five planetary nebulous spots to be annular nebulæ, having one or two central stars. The largest of these planetary nebulæ is situated in the Great Bear (near β Ursæ Maj.) and was discovered by Méchain in 1781. The diameter of the disc[49] is 2′ 40″. The planetary nebula in the Southern Cross (No. 3365, *Observations at the Cape*, p. 100), with a disc having a diameter scarcely equal to 12″, exhibits the brightness of a star of the 6·7th magnitude. Its light is indigo-blue, and the

[49] If we consider the planetary nebula in the Great Bear to be a sphere having an apparent diameter of 2′ 40″, "and assume its distance to be equal to the known distance of 61 Cygni, we shall obtain an actual diameter for the sphere, which is seven times greater than the orbit described by Neptune."—*Outlines*, § 876.

same colour, which is very remarkable in nebulæ, is observed in three other objects of the same form, although in the latter the blue is less intense.[80] The blue colour of some planetary nebulæ does not militate against the possibility of their being composed of small stars; for we find blue stars not only as the individual members of a pair of double-stars, but even stellar clusters composed entirely of blue stars, or of the latter interspersed with small red and yellow stars.[81]

The question whether planetary nebulæ are very remote nebulous stars, in which our telescopic vision is unable to recognize the difference between a luminous central star, and the vaporous envelope surrounding it, has already been considered in the beginning of my *Delineation of Nature.*[82] Would that Lord Rosse's colossal telescope might finally be the means of elucidating the nature of these remarkable planetary vaporous discs! Although there is considerable difficulty in acquiring a clear conception of the complicated dynamic

[80] *Outlines*, p. 603; *Observations at the Cape*, § 47. There is an orange-red star of the eighth magnitude in the vicinity of No. 3365; but the planetary nebula retains its deep indigo-blue colour when the red star is not in the field of the telescope. The colour is, therefore, not the effect of contrast.

[81] *Cosmos*, vol. iii. pp. 184, 283, and note. The companion and the main-star are blue, or bluish, in more than 63 double stars. Indigo-blue stars are intermixed in the splendid, many-coloured clusters of stars, No. 3435 of the Cape Catalogue (Dunlop's *Catalogue*, No. 301). An entirely uniform blue cluster of stars is observed in the southern heavens. (No. 573 of Dunlop; No. 3770 of Sir John Herschel.) This cluster has a diameter of 3½′, with prolongations measuring 8′ in length; the stars are of the 14th and 16th magnitude. (*Observations at the Cape*, p. 119.)

[82] *Cosmos*, vol. i. p. 68 and note. Compare *Outlines*, § 877.

conditions under which, in a globular or spheroidally flattened stellar cluster, the rotating crowded suns, whose specific density is greater towards the centre, constitute a system of equilibrium;[83] this difficulty increases still more in those circular, well-defined, planetary, nebulous discs which exhibit a perfectly uniform brightness, without any increase of intensity towards the centre. Such a condition seems to depend less upon sphericity of form (the state of aggregation of many thousand small stars,) than on the existence of a gaseous photosphere, which is supposed, as in our Sun, to be covered with a thin, untransparent, or very faintly illuminated stratum of vapour. Does the light in the planetary nebulous disc appear to be thus uniformly diffused, simply in consequence of the great distance, which causes the difference between the centre and the margins to disappear?

The fourth and last order of *regular* nebulæ comprises Sir William Herschel's *nebulous stars*, *i. e.* true stars surrounded by a milky nebula, which is very probably connected with, and dependent upon, the central star. Very different opinions exist as to whether the nebula, which, according to Lord Rosse and Mr. Stoney, appears to be perfectly annular in some of these groups (*Philos. Transact.* for 1850, pl. xxxviii. figs. 15 and 16), is self-luminous, forming a photosphere like our Sun, or whether) which, however, is less pro-

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[83] On the development of the dynamic relations manifested in the partial attractions in the interior of a globular cluster of stars, which appears in a telescope of weak power, as a round nebula increasing in density towards the centre, see Sir John Herschel, in *Outlines of Astronomy*, § 866 and 872; *Observations at the Cape*, § 44, 111 to 113; *Philos. Transact.* for 1833, p. 501; *Address of the President in the Report of the Fifteenth Meeting of the British Association*, 1845, p. xxxvii.

bable) it is simply illumined by the central Sun. It was the opinion of Derham, and to some extent also of Lacaille, who discovered many nebulous stars at the Cape of Good Hope, that the stars were situated far from the nebulæ on which they were projected. Mairan appears (1731) first to have expressed the view that nebulous stars are surrounded by an atmosphere of light appertaining to them.[54] We even find that some of the larger stars (of the 7th magnitude, for instance, as No. 675 of the Catalogue of 1833), have a photosphere, whose diameter measures from 2′ to 3′.[55]

The large nebulous masses of irregular configuration compose a class of nebulæ differing entirely from those we have described as *regular*, and which are, at all events, faintly defined. They are characterized by the most variously unsymmetrical forms, having indefinite and confused outlines. These bodies, which constitute mysterious phenomena *sui generis*, have mainly given occasion to the opinions advanced in reference to the existence of *cosmical clouds* and *self-luminous nebulæ*, supposed to be distributed through the regions of space, and to resemble the substratum of the zodiacal light. These *irregular* nebulæ, which cover a portion of the firmament several square degrees in extent, present a striking contrast with the smallest of all the *regular* isolated and oval nebulous discs, which is equal in luminous intensity to a telescopic star of the 14th magnitude, and is situated between the constellations Ara

[54] Mairan, *Traité de l'Aurore boréale*, p. 263; Arago, in the *Annuaire pour* 1842, pp. 403–413.

[55] In other instances these nebulous stars are only of the eighth to the ninth magnitude; as Nos. 311 and 450 of the Catalogue of 1833, fig. 31, having photospheres of 1′ 30″. (*Outlines*, § 879.)

and Apus, in the southern hemisphere.[86] No two of the unsymmetrical, diffused nebulous masses resemble one another;[87] but, adds Sir John Herschel, from the experience of many years' observation, one thing observed in reference to them, and which gives them a peculiar character, is, that all are situated within or very near to the margins of the Milky Way, and may be regarded as off-shoots from it. On the contrary, the regularly shaped and well-defined small nebulous spots are partly scattered over the whole heavens, and partly compressed together in special regions, far from the Milky Way, as, for instance, in the northern hemisphere, in the regions of Virgo and Pisces. Although the large irregular nebulous mass in the sword of Orion is certainly situated at a considerable distance from the visible margin of the Galaxy (fully 15°), still even it may perhaps belong to that prolongation of its branch which appears to lose itself from α and ϵ Persei towards Aldebaran and the Hyades, and to which we have already referred at p. 199. The brilliant stars which gave early celebrity to the constellation of Orion,

[86] *Observations at the Cape*, p. 117, no. 3727. pl. vi. fig. 16.

[87] We meet with remarkable forms of irregular nebulæ, as, for instance, the omega-shaped (*Observations at the Cape*, pl. ii. fig. 1, No. 2008), which has been investigated and described by Lamont, and by a meritorious North American astronomer, Mr. Mason, whose early loss is much to be lamented (*Mem. of the Amer. Philos. Society*, vol. vii. p. 117); a nebula having from 6 to 8 nuclei (*Observations at the Cape*, p. 19, pl. iii. fig. 4); the cometary tuft-like form in which the nebulous rays seem occasionally to expand, as from a star of the ninth magnitude (pl. vi. fig. 18, Nos. 2534 and 3688); a silhouette profile, or bust-like outline (pl. iv. fig. 4, No. 3075); a fissure-like opening, inclosing a filiform nebula. (No. 3501, pl. iv. fig. 2; *Outlines*, § 883; *Observations at the Cape*, § 121.)

are, moreover, reckoned to belong to that zone of very large, and probably less remote stars, whose prolonged direction indicates the vast circle of the Southern Galaxy, passing through *ε* Orionis and *α* Crucis.[58]

The opinion which at one time prevailed so extensively[59] of the existence of a *galaxy of nebulæ* intersecting the stellar Milky Way almost at right angles, has not been confirmed by more recent and accurate observations in reference to the distribution of symmetrical nebulæ in the firmament.[60] There certainly are, as has already been observed, very great accumulations at the northern pole of the Galaxy, while a very considerable abundance of nebulous matter is also observed at the south galactic pole near Pisces; but in consequence of the many interruptions which break the zone, we are unable to indicate any large circle connecting these poles together, and formed by a continued line of nebulæ. William Herschel, in advancing this view in 1784, at the close of his first treatise on the structure of the heavens, developed it with a caution worthy of such an observer, and from which doubt was not entirely excluded.

Some of the irregular, or rather unsymmetrical nebulæ

[58] *Cosmos*, vol. iii. p. 199. *Outlines*, § 785.

[59] *Cosmos*, vol. i. p. 141 and note; Sir John Herschel's first edition of his *Treatise on Astronomy*, 1833, in *Lardner's Cabinet Cyclopædia*, § 616; Littrow, *Theoretische Astronomie*, 1834, th. ii. § 234.

[60] See *Edinburgh Review*, January, 1848, p. 187, and *Observations at the Cape*, § 96, 107. "The distribution of the nebulæ is not like that of the Milky Way," says Sir John Herschel, "in a zone or band encircling the heavens; or if such a zone can be at all traced out, it is with so many interruptions, and so faintly marked out through by far the greater part of its circumference, that its existence as such can be hardly more than suspected."

(as those in the sword of Orion, near η Argûs, in Sagittarius and in Cygnus), are remarkable for their extraordinary size; others, (as Nos. 27 and 51 of Messier's Catalogue) for their singular forms.

It has already been noticed in reference to the *large nebula in the sword of Orion*, that Galileo never mentioned it although he devoted so much attention to the stars between the girdle and the sword,[81] and even sketched a map of this region of the heavens. That which he names *Nebulosa Orionis*, and delineates in the vicinity of *Nebulosa Præsepe*, he expressly declares to be an accumulation of small stars, (*stellarum constipatarum*) in the *head of Orion*. In the drawing which he gives in the *Siderius Nuncius*, § 20, extending from

[81] "There can be no doubt," writes Dr. Galle, "that the drawing" (*Opere di Galilei*, Padova, 1744, tom. ii. p. 14, No. 20,) "which you gave me includes the girdle and sword of Orion, and consequently also the star θ, but it is difficult, owing to the striking inaccuracy of the drawing, to recognize the three small stars in the sword (the middle one of which is θ), and which appear to the unaided eye to be placed in a straight line. I conjecture that you have correctly designated the star ι, and that the bright star to the right and below, or the one immediately above it, is θ." Galileo expressly says, "In primo integram Orionis Constellationem pingere decreveram: verum, ab ingenti stellarum copiâ, temporis vero inopia obrutus, aggressionem hanc in aliam occasionem distuli." Considering Galileo's observation of the constellation of Orion, we are the more struck by the circumstance that the 400 stars which he thought he had counted between the girdle and the sword of Orion in a space of ten square degrees (Nelli, *Vita di Galilei*, vol. i. p. 208), should subsequently (according to Lambert, *Cosmolog. Briefe*, 1760, p. 155,) have led him to the erroneous estimate of 1,650,000 stars for the whole firmament. (Struve, *Astr. stellaire*, p. 14 and note 16.)

the girdle to the beginning of the right leg (α Orionis), I recognize the multiple star θ above the star ι. The instruments employed by Galileo did not magnify more than from eight to thirty times. It is probable that as the nebula in the sword is not isolated, but appears, when seen through imperfect instruments or a hazy atmosphere, like a halo round the star θ, its individual existence and configuration may have escaped the notice of the great Florentine observer. He was moreover little inclined to assume the existence of nebulæ.[a] It was not until fourteen years after Galileo's death, in the year 1656, that Huygens first observed the great nebula of Orion of which he gave a rough sketch in the *Systema Saturnium*, which appeared in 1659. "While," says this great man, "I was observing, with a refractor of twenty-five feet focal length, the variable belts of Jupiter, a dark central belt in Mars and some faint phases of this planet, my attention was attracted by an appearance among the fixed stars, which, as far as I know, has not been observed by any one else, and which, indeed, could not be recognized, except by such powerful instruments as I employ. Astronomers enumerate three stars in the sword of Orion, lying very near one another. On one occasion when, in 1656, I was accidentally observing the middle one of these stars through my telescope, I saw twelve stars instead of a single one, which, indeed, not unfrequently happens, in using the telescope. Three of this number were almost in contact with one another, and *four* of them shone as if through a mist, so that the space around them, having the form drawn in the appended figure, appeared much brighter than the rest of the sky, which was perfectly clear, and looked almost black. This appearance

[a] *Cosmos*, vol. ii. p. 714.

cated, therefore, almost as if there were a *hiatus* or interruption. I have frequently observed this phenomenon, and up to the present time as always unchanged in form; whence it would appear that this marvellous object, be its nature what it may be, is very probably permanently situated at this spot. I never observed anything similar to this appearance in the other fixed stars." (The nebulous spot in Andromeda, described fifty-four years earlier by Simon Marius, must therefore either have been unknown to him, or did not attract his attention.) That which has usually been regarded as nebulous matter, adds Huygens, "even the Milky Way, when seen through telescopes, exhibits nothing nebulous, and is nothing more than a multitude of stars, thronged together in clusters."[63] The animation of this first description tes-

[63] "Ex his autem tres illæ pene inter se contiguæ stellæ, cumque his aliæ quatuor, velut trans nebulam lucebant: ita ut spatium circa ipsas, qua forma hic conspicitur, multo illustrius appareret reliquo omni cœlo; quod cum apprime serenum esset ac cerneretur nigerrimum, velut hiatu quodam interruptum videbatur, per quem in plagam magis lucidam esset prospectus. Idem vero in hanc usque diem nihil immutata facie sæpius atque eodem loco conspexi; adeo ut perpetuam illic sedem habere credibile sit hoc quidquid est portenti: cui certe simile aliud nusquam apud reliquas fixas potui animadvertere. Nam cæteræ nebulosæ olim existimatæ, atque ipsa via lactea, perspicillo inspectæ, nullas nebulas habere comperiuntur, neque aliud esse quam plurium stellarum congeries et frequentia."—Christiani Hugenii, *Opera varia*, Lugd. Bat. 1724, pp. 540–541. "Of these, however, those three almost contiguous stars, and, with these, four others shone, as it were, through a nebula; so that the space around them, as is shown in this figure, is much more brilliant than all the rest of the sky; and when this is very serene and appears quite dark, it seemed broken by a sort of gap, through which one looked upon a brighter region

tifies the freshness and depth of the impressions produced on his mind, but how great is the distance from this first sketch made in the middle of the seventeenth century, and the somewhat less imperfect descriptions of Picard, Le Gentil, and Messier, to the admirable delineations of Sir John Herschel (1837), and of William Cranch Bond (1848), the Director of the Observatory at Cambridge, U.S.![64]

The former of these two astronomers had the great advantage[65] of observing the nebula in Orion, since 1834, at the Cape of Good Hope, at an altitude of 60°, and with a twenty-

behind. The same thing I have since beheld over and over again, without any change in its appearance and in the same position, so that one might almost believe that this marvellous object, whatever it is, is permanently fixed there; it is certain I have nowhere else noticed anything similar to this in the other fixed stars. For those which have generally been considered as nebulæ, and even the Milky Way itself, when seen through a telescope, are found to have nothing nebulous about them, but are nothing more than a multitude of several stars clustered together." Huygens himself estimated the powers he employed in his twenty-five feet refractor as equal to a hundred diameters (p. 538). Are the "quatuor stellæ trans nebulam lucentes" the stars of the trapezium? The small and very rough sketch (Tab. xlvii. fig. 4, *Phenomenon in Orione Novum.*) represents only a group of three stars, near an indentation which one might certainly regard as the *Sinus Magnus*. Perhaps the drawing gives only the three stars in the trapezium, which range from the fourth to the seventh magnitude. Dominique Cassini moreover boasts that he was the first who observed the fourth star.

[64] William Cranch Bond, in the *Transactions of the American Academy of Arts and Sciences*, new series, vol. iii. pp. 87–96.

[65] *Observations at the Cape*, § 54–69, pl. viii.; *Outlines*, § 837 and 885, pl. iv. fig. 1.

feet reflector, by which means he was enabled to render his earlier delineations of 1824–1826 more perfect.[66] The positions of 150 stars, mostly of from the fifteenth to the eighteenth magnitudes, in the vicinity of θ Orionis were determined. The celebrated trapezium, which is not surrounded by a nebula, is formed of four stars of the fourth, sixth, seventh, and eighth magnitudes. The fourth star was discovered (in 1666?) by Dominique Cassini, at Bologna;[67] the 5th (γ') in 1826, by Struve; and the sixth (a'), which is of the thirteenth magnitude, in the year 1832, by Sir John Herschel. De Vico, the Director of the Observatory at the Collegio Romano, announced in the beginning of the year 1839, that he had discovered three other stars in the trapezium with his great Cauchoix refractor. These have not been observed either by Sir John Herschel or Mr. Bond. That portion of the nebula nearest the almost unnebulous trapezium, and forming, as it were, the anterior part of the head above the throat, the *regio Huygeniana*, is speckled, and of a granular texture, and has been resolved into clusters of stars both by Lord Rosse's colossal telescope and by the large Cambridge (U.S.) refractor.[68] Many positions of the smaller

[66] Sir John Herschel, in the *Memoirs of the Astronomical Society*, vol. ii. 1824, pp. 487–495, pl. vii. viii. The latter of these gives the nomenclature of the separate regions of the nebula in Orion, which have been explored by so many astronomers.

[67] Delambre, *Hist. de l'Astron. moderne*, tom. ii. p. 700. Cassini reckoned the appearance of this fourth star ("aggiunta della quarta stella alle tre contigue,") among the changes which had taken place in the nebula of Orion in his time.

[68] "It is remarkable, however, that within the area of the trapezium no *nebula* exists. The general aspect of the less luminous and cirrous portion is simply nebulous and irresolvable, but the brighter portion, immediately adjacent to the

stars have been determined by accurate observers of the present day; as, for instance, Lamont at Munich, and Cooper and Lassell in England. The first named of these employed a 1,200-fold magnifying power. Sir William Herschel was of opinion, from a comparison of his own observations made with the same instruments, from 1783 to 1811, that alterations had taken place in the relative brilliancy and in the outlines of the great nebula of Orion.[60] Bouilland and Le Gentil had maintained the same opinion in reference to the nebula in Andromeda; but the thorough investigations of Sir John Herschel have rendered the occurrence of any such cosmical changes, although formerly considered to be well established, exceedingly doubtful, to say the least.

The large nebula round η Argûs, is situated in that portion of the Milky Way, which extends from the feet of the Centaur, through the Southern Cross, towards the middle part of Argo, and is so distinguished by the intensity of its mag-

trapezium, forming the square front of the head, is shown with the eighteen-inch reflector broken up into masses (very imperfectly represented in the figure), whose mottled and curdling light evidently indicates, by a sort of granular texture, its consisting of stars, and when examined under the great light of Lord Rosse's reflector, or the exquisite defining power of the great achromatic at Cambridge, U. S., is evidently perceived to consist of clustering stars. There can, therefore, be little doubt as to the whole consisting of stars, too minute to be discerned individually even with these powerful aids, but which become visible as points of light when closely adjacent in the more crowded parts."—(*Outlines*, p. 609.) William C. Bond, who made use of a twenty-five feet refractor, having a fourteen-inch object-glass, says, "There is a great diminution of light in the interior of the trapezium, but no suspicion of a star." (*Memoirs of the American Academy*, new series, vol. iii. p. 93.)

[60] *Philos. Transact.* for the year 1811, vol. ci. p. 324.

nificent effulgence. The light emanating from this region is so extraordinary that Captain Jacob, an accurate observer, and a resident in the tropical parts of India, remarks, entirely in harmony with my prolonged experience: "Such is the general blaze from that part of the sky, that a person is immediately made aware of its having risen above the horizon, though he should not be at the time looking at the heavens, by the increase of general illumination of the atmosphere, resembling the effect of the young Moon."[70]

The nebula, in the midst of which lies the star η Argûs, which has become so celebrated for the alterations observed in the intensity of its light, covers a space of more than $\frac{4}{7}$ths of a square degree.[71] The nebula itself, which is divided into many unsymmetrical masses of unequal luminous intensity, nowhere exhibits the speckled, *granular* appearance which admits of the assumption of its resolvability. It incloses a singularly shaped, oval *vacancy*, covered with a faint glimmer of light. A fine delineation of the entire appearance, the result of two months' measurements, is given in Sir John Herschel's *Observations at the Cape*.[72] This observer determined no less than 1,216 positions of stars, mostly from the fourteenth to the sixteenth magnitudes, in the nebula of η Argûs. These extend far beyond the nebula into the Milky Way, where they stand clearly forth on the deep black ground of the sky, and they are probably, therefore, unconnected with, and far removed from, the nebula itself. The whole contiguous portion of the Milky Way is, moreover, so rich in stars (not clusters), that

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[70] *Transact. of the Royal Society of Edinburgh*, vol. xvi. 1849, part iv. p. 445.

[71] *Cosmos*, vol. iii. pp. 240–243.

[72] *Observ. at the Cape*, § 70–90, pl. ix. *Outlines*, § 887, pl. iv. fig. 2.

by means of the telescopic star-gauges 3.138 stars have been found for every mean square degree between R. A. 9h. 50m. and 11h. 34m. These numbers even increase to 5,093 in the sweeps for R. A. 11h. 24m. that is to say, for one square degree of the firmament, a number of stars greater than those which are visible to the naked eye in the horizon of Paris or Alexandria, from the first to the sixth magnitude.[73]

The nebula in Sagittarius, which is of considerable size, appears as if composed of four separate masses (R. Asc. 17h. 53m.; N. P. Decl. 114° 21′), one of which is again three-membered. All are interrupted by spots free from nebulous matter, and the whole was imperfectly observed by Messier.[74]

The nebulæ in Cygnus are several irregular masses, one of which forms a very narrow divided band, passing through the double star η Cygni. Mason was the first to recognize the connection of these masses, so widely different, by means of a singular cellular tissue.[75]

The nebula in Vulpes was imperfectly seen by Messier (No. 27 of his Catalogue) when he was making an observation of Bode's Comet in 1779. Sir John Herschel was the first who delineated and accurately determined its position (R. Asc. 19° 52′; N. P. Decl. 67° 43′). This nebula, which is not of an irregular form, first received the name of the "Dumb-bell," on the application of a reflector with an eighteen-inch aperture. (*Philos. Transact.* for 1833, No. 2060, fig. 26;

[73] *Cosmos*, vol. iii. p. 142.

[74] *Observ. at the Cape.* § 24, pl. 1. fig. 1. No. 3721 of the Catalogue; *Outlines*, § 888.

[75] The nebula in Cygnus, partly in R. Asc. 20h. 49m.; N. P. Decl. 58° 27′. (*Outlines*, § 891.) Compare Catalogue of 1833, No. 2092, pl. xi. fig. 34.

Outlines, § 881.) This similarity to a dumb-bell entirely disappeared in Lord Rosse's reflector of three-feet aperture.[76] (See his recent important delineation. *Philos. Transact.* for 1850, pl. xxxviii. fig. 17.) It was also successfully resolved into numerous stars; which, however, continued mixed with nebulous matter.

The spiral nebula in the more northern of the Canes Venatici was discovered by Messier on the 13th of October, 1773 (on the occasion of his discovery of the Comet), in the left ear of Asterion, very near η (Benetnasch) in the tail of the Great Bear (No. 51 of Messier, and No. 1622 of the great Catalogue published in the *Philos. Transact.* for 1833, p. 496, fig. 25.) This is one of the most remarkable phenomena in the firmament, both on account of its singular configuration, and of the unexpected transformative effect produced on its appearance by Lord Rosse's six-feet speculum. In Sir John Herschel's eighteen-inch reflector, the nebula presented the appearance of a spherical body, surrounded by a far distant ring, so that it exhibited, as it were, an image of our starry stratum with its galactic ring.[77] But in the spring of 1845, the large Parsonstown telescope transformed the whole into a helicine twisted coil—a luminous spiral, whose convolutions appear unequal, and are prolonged at both extremities, both in the centre and outwards, into dense, granular, globular nodules. Dr. Nichol made a drawing of this object,

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[76] Compare pl. ii. fig. 2 with pl. v. in *Thoughts on some important points relating to the system of the world*, 1846, (by Dr. Nichol, Professor of Astronomy at Glasgow), p. 22. "Lord Rosse," says Sir John Herschel, *Outlines*, p. 607, "describes and figures it as resolved into numerous stars with much intermixed nebula."

[77] *Cosmos*, vol. i. p. 141 and note, where the nebula, No. 1622, is termed a "brother-system."

which was laid before the Meeting of the British Association at Cambridge, in 1845, by Lord Rosse.[78] But the most perfect delineation of this nebula has been given by Mr. Johnstone Stoney. (*Philos. Transact.* 1850, part i. pl. xxxv. fig. 1.) A similar spiral form is observed in No. 99 of Messier's Catalogue, which presents also a single central nucleus, and in other northern nebulæ.

It still remains for us to notice, more circumstantially than could be done in "the general delineation of Nature,"[79] an object which is unparalleled in the world of forms exhibited throughout the firmament, and by which the *picturesque effect* of the southern hemisphere—if I may be permitted to use the expression—is heightened. The two Magellanic Clouds, which were probably first named Cape Clouds by Portuguese, and subsequently by Dutch and Danish pilots,[80] most strongly rivet the attention of travellers, as I can testify from personal experience, by the intensity of their light, their individual isolation and their common rotation round the South Pole, although at different distances from it. We learn from the express mention and definite description of these circling clouds of light by the Florentine, Andrea Corsali, in his travels to Cochin, and by the Secretary of

[78] *Report of the Fifteenth Meeting of the British Association for the Advancement of Science, Notices*, p. 4; Nichol, *Thoughts*, p. 23. (Compare pl. ii. fig. 1, with pl. vi.) In the *Outlines*, § 882, we find the following passage: "The whole, if not clearly resolved into stars, has a resolvable character, which evidently indicates its composition."

[79] *Cosmos*, vol. i. p. 69 and note.

[80] Lacaille, in the *Mém. de l'Acad.* année 1755, p. 195. This is an unfortunate confusion of terminology, in the same manner as Horner and Littrow call the Coal-bags *Magellanic spots*, or *Cape Clouds*.

Ferdinand the Catholic, Petrus Martyr de Anghiera, in his work *De rebus Oceanicis et Orbe novo* (dec. i. lib. ix. p. 96), that the designation which refers to Magellan's circumnavigation is not the older name.[81] For the notices here indicated are both of the year 1515; whilst Pigafetta, the companion of Magellan, does not mention the *nebbictte* in his journal earlier than January, 1521, when the ship "Victoria" passed through the Patagonian Straits into the South Sea. The very old designation of "Cape Clouds" did not, moreover, arise from the vicinity of the more southern constellation of "Table mount," since the latter was first introduced by Lacaille. The name would more probably seem to refer to the actual Table Mountain, and to the appearance of a small cloud on its summit, which was dreaded by mariners as portending the coming of a storm. We shall presently see that both the *nubeculæ*, which had been long observed in the southern hemisphere, although not definitely named, acquired with the spread of navigation, and the increasing animation of certain commercial routes, designations which were derived from these very routes themselves.

The constant navigation of the Indian Ocean, washing the shores of Eastern Africa, was the earliest means—especially since the time of the Lagides and the Monsun-navigation—of making mariners acquainted with the stars near the Southern Pole. As early as the middle of the tenth century, we find, as already observed, that the Arabs had given a name to the larger of the Magellanic Clouds. This designation is, according to Ideler's researches, identical with that of the *White Ox, el-bakar* of the celebrated astronomer, Derwisch Abdurrahmán Sufi of Raï, a city in the Persian province of Irak. In his *Introduction to the knowledge of the starry heavens,*

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[81] *Cosmos*, vol. ii. p. 665 and note.

which he composed at the Court of the Sultans of the dynasty of the Buyides, he says that "below the feet of the *Suhel* (by which he expressly means the Suhel of Ptolemy, Canopus, although the Arabian astronomers named many other large stars of Argo, *el-sefina*, Suhel.) there is a 'white spot,' which is invisible both in Irak (in the district of Bagdad and in Nedsch, 'Nedjed,') and in the more northern and mountainous part of Arabia; but may be seen in the Southern Tehama, between Mecca and the extremity of Yemen, along the coast of the Red Sea."[82] The relative position of the *White Ox* to Canopus, is here indicated with sufficient accuracy for the naked eye; for the Right Ascension of Canopus is 6h. 20m., and the eastern margin of the larger Magellanic Clouds lies in Right Ascension 6h. The visibility of the *Nubecula major* in northern latitudes cannot have been appreciably affected by the precession of the equinoxes since the tenth century, for the maximum distance from the north was attained during the succeeding ten centuries If we follow the recent determination of position for the larger cloud by Sir John Herschel, we shall find that it was perfectly visible as far north as 17° in the time of Abdurrahman Sufi; at the present time it is seen in about 18° north latitude. The southern clouds must therefore have been visible throughout the whole of south-western Arabia, in Hadhramaut (noted for its frankincense) as well as in Yemen, the ancient seat of civilization

[82] Ideler, *Untersuchungen über den Ursprung und die Bedeutung der Sternnamen*, 1809, p. xlix. 262. The name Abdurrahman Sufi was contracted by Ulugh Beg from Abdu-r-rahman Ebn-Omar Ebn-Mohammed Ebn-Sahl Abu'l-Hassan el-Sufi el-Razi. Ulugh Beg, who like Nassir-eddin, amended the Ptolemaic star-positions from his own observations (1437), admits that he borrowed from Abdurrahman Sufi's work, the positions of 27 southern stars, not visible at Samarcand.

of Saba, and the long established colony of the Joctanides. The southernmost extremity of Arabia, at Aden, on the Straits of Bab-el-Mandeb, is situated in 12° 45′, and Loheia in 15° 44′ north latitude. The settlement of many Arabian colonies on the eastern coast of Africa between the tropics, north and south of the equator, naturally led to a more special knowledge of the southern stars.

The western coasts of Africa beyond the line were first visited by some of the more cultivated European pilots (especially Catalanians and Portuguese). Undoubted documents, such as the Map of the World of Marino Sanuto Torsello, of the year 1306, the Genoese *Portulano Mediceo* (1351), the *Planisferio de la Palatina* (1417), and the *Mappa-mondo* di Fra Mauro Camaldolese (between 1457 and 1459); prove that the triangular configuration of the southern extremity of the African Continent was known 178 years before the so-called *first* discovery of the *Cabo Tormentoso* (Cape of Good Hope), by Bartholomæus Diaz, in the month of May, 1487.[83] The importance of such a commercial route, rapidly increasing from the time of Gama's expedition, was, on account of the common aim of all West-African voyages, the occasion of the two Southern Clouds being designated by the pilots *Cape*

[83] See my geographical investigations on the discovery of the southern extremity of Africa, and on the statements of Cardinal Zurla and Count Baldelli in the *Examen crit. de l'Hist. de la Géographie aux quinzième et seizième siècles*, tom. i. pp. 229–348. The discovery of the Cape of Good Hope, which Martin Behaim calls the *Terra Fragosa*, and not *Cabo Tormentosa*, was made, singularly enough, when Diaz came *from the east* (from the Bay of Algoa, 33° 47′ south latitude, and more than 7° 18′ east of Table Bay). Lichtenstein, in *Das Vaterländische Museum*, Hamburgh, 1810, § 372–389.

Clouds, as remarkable celestial phenomena seen during *voyages to the Cape.*

The constant endeavours made to advance along the eastern shores of America, beyond the equator, and even to the southern extremity of the continent, directed the attention of mariners uninterruptedly to the southern stars, from the period of Alonso de Hojeda's expedition, in which Amerigo Vespucci took part (in 1499), to that of Magellan and Sebastian del Cano in 1521, and of Garcia de Loaysa,[84] with Francisco de Hoces in 1525. It would appear from the journals still extant, and from the historical testimony of Anghiera, that the southern stars were made the special objects of attention during the voyage in which Amerigo Vespucci and Vicente Yañez Pinzon discovered Cape San Augustin in 8° 20′ south latitude. Vespucci boasts on this occasion of having seen three *Canopi* (one dark, *Canopo fosco;* and two bright stars, *Canopi risplendenti*). We find from an attempt made by Ideler, the ingenious author of works on the "Names of the Stars" and on "Chronology," to explain Vespucci's very confused description of the southern heavens, in his letter to Lorenzo Pierfrancesco de' Medici, of the party of the "Popolani," that Vespucci used the name in nearly as indefinite a manner as the Arabian

[84] The merit of the discovery of the southernmost extremity of the new continent in 55° south latitude (whose importance has not been sufficiently estimated), is due to Francis de Hoces, who commanded one of the ships of the expedition of Loaysa in 1525. It is very characteristically described in Urdaneta's Journal by the words *acabamiento de tierra*, "the ceasing of land." De Hoces probably saw a portion of Terra del Fuego west of Staten Island, for Cape Horn is situated, according to Fitzroy, in 55° 58′ 41″. See Navarrete, *Viages y descubrim. de los Españoles*, tom. v. pp. 28, 404.

astronomers had used the word *Suhel*. Ideler shows that the "*Canopo fosco nella via lattea*," must have been the black spot, or large coal-sack in the Southern Cross; while the position of three stars, in which are supposed to be recognized α, β, and γ of Hydrus, renders it very probable that the "*canopo risplendente di notabile grandezza*," (of considerable extent) is the Nubecula major, and the second *risplendente* the Nubecula minor.[85] It is very singular that Vespucci should not have compared these recently-noticed celestial objects to clouds, as all other observers had done. One would have thought the comparison irresistible. Peter Martyr Anghiera, who was personally acquainted with all the discoverers, and whose letters were written under the vivid impression excited in his mind by their narratives, describes, with striking truthfulness, the mild, but unequal effulgence of the nubeculæ. He says: "Assecuti sunt Portugallenses alterius poli gradum quinquagesimum amplius, ubi punctum, (polum?) circumeuntes *quasdam nubeculas* licet intueri, veluti in lactea via sparsos fulgores per universi cœli globum intra ejus spatii latitudinem."[86]* The exceeding fame,

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[85] Humboldt, *Examen crit. de la Géogr.* tom. iv. pp. 205, 295–316; tom. v. pp. 225–229, 235. Ideler, *Sternnamen*, § 346.

[86] Petrus Martyr Angh. *Oceanica*, dec. iii. lib. i. p. 217, I can prove from the numerical data in dec. ii. lib. x. p. 204, and dec. iii. lib. x. p. 232, that the portion of the *Oceanica*, in which the Magellanic Clouds are referred to, was written between 1514 and 1516, and therefore immediately after the expedition of Juan Diaz de Solis to the Rio de la Plata (then known as the *Rio de Solis, una mar dulce*). The latitudes are much exaggerated.

* "The Portuguese extended their discoveries to within less than 50 degrees of the South Pole, where they plainly observed certain nebulæ moving round the point (pole?),

and the long duration of Magellan's circumnavigation (from August, 1519, to September, 1522), and the long sojourn of a numerous crew under the southern sky, obliterated the remembrance of all earlier observations, and spread the name of the *Magellanic Clouds* among all the seafaring nations of the Mediterranean.

We have thus shown by a single example how the extension of the geographical horizon southward opened a new field to contemplative astronomy. There were four objects to which the attention of pilots was especially directed in the new hemisphere, viz. the search for a southern polar star, the form of the Southern Cross, which assumes a vertical position when it passes through the meridian of the place of observation, the Coal-sacks, and the circling clouds of light. We learn from the treatise on the art of navigation (*Arte de Navegar*, lib. v. cap. 11), by Pedro de Medina, which has been translated into many languages, and first appeared in 1545, that the meridian altitudes of the "Cruzero" were used as early as the first half of the sixteenth century for the determinations of latitude. *Measurement* soon succeeded the merely contemplative observation. The first work on the position of stars contiguous to the antarctic pole was based on the distances of known stars of the Rudolphine Tables, as calculated by Tycho Brahe. This work, as I have already observed,[87] was composed by Petrus Theodori of Embden, and Friedrich Houtman of Holland, who navigated the Indian Seas about the year 1594. The results of their measurements were speedily embodied in the Star-Catalogues

like the luminous spots scattered in the Milky Way throughout the arch of heaven within the breadth of that space."

[87] *Cosmos*, vol. ii. p. 666; vol. iii. pp. 151, 187.

and celestial globes of Blaeuw (1601), of Bayer (1603), and of Paul Merula (1605). Such were the materials for the foundation of the topography of the southern heavens before Halley (1677), and before the meritorious astronomical researches of the Jesuits Jean de Fontaney, Richaud and Noel. The intimate connection between the history of astronomy and that of geography thus indicates those memorable epochs in which (scarcely two hundred and fifty years ago) men first acquired the knowledge necessary for the completion of the *cosmical image* of the firmament and of the configuration of continents.

The *Magellanic Clouds*, the larger of which covers a celestial space of forty-two, and the smaller a space of ten square degrees, certainly produce, at first sight, the same impression on the unaided eye as might be excited by two bright portions of the Milky Way, equal in size and isolated in position. The smaller cloud entirely disappears in clear moonlight, while the larger one only loses a considerable portion of its brightness. Sir John Herschel's delineation of these objects is admirable, and accurately corresponds with the vivid impressions excited in my own mind during my sojourn in Peru. Astronomy is indebted to the laborious researches of this observer at the Cape of Good Hope in 1837, for the first accurate analysis of this most wondrous aggregation of heterogeneous elements.[88] He found a large number of individual

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[88] *Cosmos*, vol. i. p. 69 and note. See *Observ. at the Cape*, pp. 143–164; pl. vii. gives a representation of the Magellanic Clouds as they appear to the naked eye; pl. x. the telescopic analysis of the *Nubecula Major*, and pl. xi. fig. 4 (§ 20–23), affords a special view of the nebula Doradûs. *Outlines*, § 892–896, pl. v. fig. 1, and James Dunlop in the *Philos. Transact.* for 1828, part i. pp. 147–151. So erroneous were the views of the earlier observers that the Jesuit Fontaney,

and scattered stars, stellar swarms and globular clusters of stars, and both oval regular and irregular nebulæ more closely thronged together than in the nebulous zone of Virgo and Coma Berenices. The *nubeculæ* cannot, therefore, from this condition of complicated aggregation, be regarded, as has too often been done, either as exceedingly large nebulæ, or as detached portions of the Milky Way. For with the exception of a small zone, lying between the constellation Ara and the tail of the Scorpion, globular stellar clusters and oval nebulæ are of rare occurrence in the Galaxy.[69]

The Magellanic Clouds are not connected with one another, or with the Milky Way, by any appreciable nebulous vapour. If we except the cluster of stars in the constel-

who was greatly esteemed by Dominique Cassini, and to whom we are indebted for many valuable astronomical observations in India and China wrote as follows, so recently as 1685. "Le grand et le petit nuages sont deux choses singulières. Ils ne paraissent aucunement un amas d'étoiles comme Præsepe Cancri, ni même une lueur sombre, comme la nébuleuse d'Andromède. On n'y voit presque rien avec de très grandes lunettes, quoique sans ce secours on les voye fort blancs, particulièrement le grand nuage." "The large and the small cloud are both very remarkable objects. They do not appear a mere mass of stars, like Præsepe in Cancer, nor are they a faint light, like the nebula in Andromeda. Very little is to be seen within these bodies even with large instruments, although when observed without such optical aid they appear very white, and this is especially the case with the large cloud."—*Lettre du Père de Fontaney au Père de la Chaize, Confesseur du Roi*, in the *Lettres Edifiantes*, Recueil vii. 1703, p. 78; and *Hist. de l'Acad. des Sciences dep.* 1686–1699 (tom. ii. Paris, 1733), p. 19. In my description of the Magellanic Clouds, in the text, I have exclusively followed Sir John Herschel's work.

[69] *Cosmos*, vol. iii. p. 196, and note.

lation Toucan,[90] Nubecula Minor is situated in a portion of the heavens barren of stars, and Nubecula Major in a less starless region. The form and internal structure of the latter are so involved that it presents many separate masses (as seen in No. 2878 of Herschel's Catalogue), which present an accurate image of the aggregate condition of the whole clouds. The conjecture advanced by the meritorious observer Horner, that the clouds were once parts of the Milky Way, in which we can, as it were, recognize their original place, is a myth, and quite as unfounded as the assertion that they have exhibited, since Lacaille's time, a progressive movement—an alteration of position. Their position was incorrectly given in consequence of the indistinctness of their margins, when seen through the older telescope having smaller apertures than our more recently constructed instruments; and Sir John Herschel states that the lesser cloud is inserted about 1h. Rt. Asc. out of its true position, in all celestial globes and star-maps. According to him *Nubecula Minor* lies between the meridians of 0h. 28m. and 1h. 15m. N. P. Decl. 162° and 165°; *Nubecula Major* in Rt. Asc. 4h. 40m. — 6h. 0m., and N. P. Decl. 156 and 162°. In the former he has catalogued according to right ascension and declination no less than 919 stars, nebulæ, and clusters, and in the latter 241. With a view of separating the three classes, I have counted the objects in the catalogue, which I find gives for

	Stars.	Nebulæ.	Clusters.
Nubecula Major	582	291	46
Nubecula Minor	200	37	7

The inconsiderable number of nebulæ contained in Nubecula Minor is very striking, for we find that, compared to the

[90] *Cosmos*, p. 192 and note.

nebulæ in Nubecula Major they are only as 1 : 8, while the ratio of the isolated stars is about 1 : 3. The catalogued stars, almost 800 in number, are for the most part of the 7th and 8th magnitudes; some few belong even to the 9th and 10th magnitudes. There is in the middle of the larger cloud a nebula, noticed by Lacaille, (30 Doradûs, Bode, No. 2941 of Sir John Herschel's Catalogue,) which is said to resemble no other nebulous body in form. Although it occupies scarcely $\frac{1}{500}$th of the area of the whole cloud, Sir John Herschel has determined the position of 105 stars of from the 14th to the 16th magnitude in this space. These stars are projected on the wholly unresolved, uniformly bright and unspeckled nebula.[91]

The *Black Specks* which attracted the attention of Portuguese and Spanish pilots as early as the close of the 15th and the beginning of the 16th centuries, circle round the southern pole opposite to the Magellanic Light-clouds, although at a greater distance from it. They are probably, as already remarked, the *Canopo fosco* of the "three Canopi," described by Amerigo Vespucci in his third voyage. I find the first definite notice of these spots in the 1st Decade of Anghiera's work, "*De Rebus Oceanicis*," (Dec. 1, lib. 9, ed. 1533, p. 20, *b*.) "Interrogati a me nautæ qui Vicentium Agnem Pinzonum fuerant comitati (1499), an antarcticum viderint polum; stellam se nullam huic Arcticæ similem, quæ discerni circa punctum (polum?) possit, cognovisse inquiunt. Stellarum tamen aliam, ajunt, se prospexisse faciem densamque quandam ab horizonte vaporosam caliginem, quæ oculos fere

[91] See *Observ. at the Cape*, § 20–23 and 133, the beautiful drawing, pl. ii. fig. 4, and a special map of the graphical analysis. Pl. x. as well as *Outlines*, § 896, pl. v. fig. 1.

obtenebraret."* The word *stella* is used here for a celestial constellation, and the narrators may not have explained themselves very distinctly in reference to a *caligo* which *obscured* their sight. Father Joseph Acosta, of Medina del Campo, gives a more satisfactory account of the Black Specks and the cause of this phenomenon. He compares them, in his *Historia Natural de las Indias* (lib. i. cap. 2), to the darkened portion of the Moon's disc in respect to colour and form. "As the Milky Way," he says, "is more brilliant because it is composed of denser celestial matter, and hence gives forth more light; so likewise the *Black Specks*, which are not visible in Europe, are entirely devoid of light, because they constitute a portion of the heavens which is barren, *i. e.* composed of very attenuated and transparent matter." The error of a distinguished astronomer in supposing that this description referred to the spots of the Sun,[82] seems scarcely less singular than that the missionary Richaud (1689) should have mistaken Acosta's "*manchas negras*," for the luminous Magellanic Clouds.[83]

Richaud, moreover, like the earliest pilots, speaks of the Coal-sacks in the plural, mentioning two, of which the large one was situated in the constellation of the Cross and another

* "I asked some mariners who had accompanied Vicentius Agnes Pinzo (1499), whether they saw the antarctic pole; and they told me that they did not observe any star like our North Star, which may be seen about the arctic pole, but that they noticed stars in another form, having the appearance of a dense and dark vapour rising from the horizon, which almost obscured their vision.

[82] *Cosmos*, vol. ii. pp. 665 and note.

[83] *Mém. de l'Acad. des Sciences dep.* 1666 *jusqu'à* 1699, t. vii. partie 2 (Paris, 1729), p. 206.

in Charles' Oak; the latter, according to other descriptions, was subdivided into two distinct specks These were described by Feuillée, in the early part of the eighteenth century, and by Horner (in a letter to Olbers, written from Brazil in 1804), as undefined, and having confused outlines.[94] I was unable during my residence in Peru to discover anything definite as to the Coal-sacks in Charles' Oak; and as I was disposed to ascribe this to the low position of the constellation, I applied for information to Sir John Herschel and to Rümker, the Director of the Observatory at Hamburgh, who had been in far more Southern latitudes than myself. Notwithstanding their endeavours, they were equally unsuccessful in discovering anything that could be compared for definiteness of outline and intensity of blackness with the Coal-sack in the Cross. Sir John Herschel is of opinion that we cannot speak of a plurality of Coal-sacks, unless we would include under that head every ill-defined and darker portion of the heavens, as the regions between α Centauri and β and γ Trianguli,[95] between η and θ Argûs, and more especially the barren portion of the Milky Way in the Northern heavens, between ϵ, α, and γ Cygni.[96]

The longest known *Black Speck* in the Southern Cross, and the one which is also the most striking as seen by the naked eye, is of a pear-like shape, and lies on the eastern side of that constellation, in 8° long. and 5° lat. This large space presents one visible star of the 6th to the 7th magnitude, toge-

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[94] Letter to Olbers from St. Catharina (January, 1804), in Zach's *Monatl. Correspondenz zur Beförd. der Erd-und Himmels-Kunde*, Bd. x. p. 240. See, on Feuillée's observation and rough sketch of the Black spot in the Southern Cross, Zach, *Op. cit.* Bd. xv. 1807, pp. 388–391.

[95] *Observ. at the Cape*, pl. xiii.

[96] *Outlines of Astronomy*, p. 531.

ther with a large number of telescopic stars, varying from the 11th to the 13th magnitudes. A small group of 40 stars lies nearly in the centre.[97] The paucity of stars and the contrast with the magnificent effulgence of the neighbouring heavens, are assigned as the causes of the remarkable blackness of this portion of the firmament. This opinion, which has been generally maintained since Lacaille's time,[98] has been especially confirmed by the "gauges" and "sweeps" made round the region where the Milky Way appears as if covered by a black cloud. The Coal-bag yielded from seven to nine telescopic stars for every sweep, but never an entirely blank field; while in a field of equal size the margins presented from 120 to 200 stars. This mode of explanation, which ascribes the darkness to contrast alone, did not, although perhaps incorrectly, appear quite satisfactory to me while I was in a tropical region, and remained under the vivid impression produced on my mind by the aspect of the Southern heavens. William Herschel's considerations on wholly starless regions in Scorpio and Serpentarius, and which he has termed "openings in the

[97] *Observ. at the Cape*, p. 384, No. 3407, of the catalogue of nebulæ and clusters. (Compare Dunlop in the *Philos. Transact.* for 1828, p. 149, and No. 272 of his Catalogue.)

[98] "Cette apparence d'un noir foncé dans la partie orientale de la Croix du Sud, qui frappe la vue de tous ceux qui regardent le ciel austral, est causée par la vivacité de la blancheur de la voie lactée qui renferme l'espace noir et l'entoure de tous côtés." "The appearance of deep black in the eastern portion of the Southern Cross, which strikes all who observe the heavens in those regions, is owing to the intensity of the whiteness of the Milky Way surrounding the black space on every side."—Lacaille, in the *Mém. de l'Acad. des Sciences*, année 1755 (Paris, 1761), p. 199.

heavens," led me to the idea that the starry strata lying behind one another in such regions may be less dense, or even wholly interrupted, and that our instruments being insufficient to penetrate to these last strata, "we look into the remote regions of space, as through tubes." I have already elsewhere noticed these openings,[99] and the effects of perspective on such interruptions in the starry strata have again been lately made the subject of earnest consideration.[100]

The extreme and most remote strata of self-luminous cosmical bodies,—the distances of nebulæ,—all that has been considered in the last seven sidereal or astrognostic portions of this work, fill the imagination and the speculative mind of man with images of time and space surpassing his powers of comprehension.

However wonderful are the improvements made in optical instruments within scarcely sixty years, we are at the same time too well acquainted with the difficulties of their construction to indulge in the bold and even unlicensed anticipations so ardently cherished by the intellectual Hooke from 1663 to 1665.[101] Moderation in the expectations entertained will be the most likely to lead to their fulfilment. Each succeeding generation has reaped the noblest and most exalted results from the triumphs of free intellect in the

[99] *Cosmos*, vol. i. p. 143 and note.

[100] "When we see," says Sir John Herschel, "in the Coal-sack (near *a* Crucis) a sharply defined oval space free from stars, it would seem much less probable that a conical or *tubular* hollow traverses the whole of a starry stratum, continuously extended from the eye outwards, than that a *distant* mass of comparatively moderate thickness should be simply perforated from side to side."—*Outlines*, § 792, p. 532.

[101] Lettre de Mr. Hooke à M. Auzout, in the *Mém. de l'Académie*, 1666–1699, tom. vii. partie 2, pp. 30, 73.

different stages to which art has gradually exalted itself. Without attempting to express in definite numbers the distances to which the space-penetrating powers of telescopic vision may already reach; and without attaching much confidence to such numbers, the knowledge of the velocity of light yet proclaims that the appearance of the remotest star,—the light-generating process on its surface,—is the "most ancient sensuous evidence of the existence of matter." [102]

[102] *Cosmos*, vol. i. p. 145.

β. The Solar Region.

PLANETS AND THEIR SATELLITES.—COMETS.—RING OF THE ZODIACAL LIGHT.—SWARMS OF METEOR-ASTEROIDS.

On passing, in the Uranological portion of the physical description of the universe, from the heaven of the fixed stars to our solar and planetary system, we descend from the great and universal to the relatively small and special. The domain of the Sun is the domain of one individual fixed star amongst the millions revealed to us in the firmament by telescopic aid—the limited space in which very various cosmical bodies, in obedience to the direct attraction of a central body, revolve around it in more or less extended orbits, whether they are isolated or encircled by other bodies similar to themselves. Among the stellar bodies whose arrangement we have endeavoured to consider in the sidereal portion of the Uranology, there is, indeed, a class of those millions of telescopic fixed stars—*double stars*—which exhibit *special*, binary, or multiple systems; but notwithstanding the analogy presented by the forces by which they are impelled, they yet differ in their natural character from our solar system. In them, self-luminous fixed stars revolve round one common centre of gravity, which is not filled with visible matter; while in our solar system *dark* cosmical bodies rotate around a self-luminous body; or, to speak more definitely, around one common centre of gravity, which lies at different times either within or without the central body. "The great

ellipse which the Earth describes round the Sun, is reflected in a small perfectly similar one, in which the central point of the Sun moves round its own and the Earth's common centre of gravity." In general notices like the present, we need hardly enter into any special consideration of the question as to whether the planetary bodies, among which we must class *interior* and *exterior* comets, may not be capable, at least in part, of generating some special light of their own, in addition to that which they receive from the central body.

We have hitherto acquired no direct evidence of the existence of dark planetary bodies revolving round other fixed stars. The faintness of the reflected light would prevent their ever being visible to us, if, as Kepler conjectured (long before Lambert) such bodies actually revolve round every fixed star. If the nearest fixed star, α Centauri, be 226,000 times the Earth's distance, or 7,523 times the distance of Neptune; if a very distant comet, that of 1680 (to which has been ascribed, although on very uncertain data, a revolution of 8,800 years), is twenty-eight times the distance of Neptune from our solar system when in its aphelion, then the distance of the fixed star α Centauri is still 270 times greater than the distance of our solar system from the aphelion of the most remote comet. The light of Neptune is reflected to us from a distance thirty times greater than our distance from the Sun. If, by the future construction of more powerful telescopes, three additional planets should be recognized, each situated at about 100 times the Earth's distance from the other, even this would not amount to the eighth part of the distance intervening to the aphelion of the comet referred to; or to the 2,200th part of the distance[1]

[1] See *Cosmos*, vol. i. pp. 95, 138, where I based my calculations on the distance of Uranus, which then constituted

which the reflected light of a satellite revolving round *α* Centauri would have to traverse in order to reach our telescopic vision. But is it absolutely necessary that we should assume the existence of satellites around the fixed stars? For when we cast a glance at the subordinate particular systems within our large planetary system, we find that, notwithstanding the analogies which may present themselves in planets attended by many satellites, there are others, such as Mercury, Venus, and Mars, which have no attendant moons. If we disregard that which is merely possible, and limit ourselves to the consideration of that which is actually

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the extreme known boundary of the planetary system. If we assume the distance of Neptune from the Sun to be 30·04 times that of the Earth, the distance of *α* Centauri from the Sun would still be 7523 times that of Neptune, the parallax being assumed as 0″·9128 (*Cosmos*, vol. iii. p. 261), yet the distance of 61 Cygni is nearly two and a half, and that of Sirius (with a parallax of 2″·230) four times that of *α* Centauri. [The distance of Neptune from the Sun is about 2,484 millions of geographical miles, and that of Uranus, according to Hansen, about 1,586 millions; the distance of Sirius amounts, according to Galle, assuming the parallax computed by Henderson, to 896,800 radii of the Earth's orbit, or 74,188,000 millions of geographical miles, a distance which gives fourteen years for the passage of light.] The aphelion of the Comet of 1680 is forty-four times the distance of Uranus, and therefore twenty-eight times that of Neptune from the Sun. According to these assumptions the Sun's distance from the star *α* Centauri is nearly 270 times that of this Comet in its aphelion, which we regard as the minimum of the very bold estimates of the radius of the solar system (see p. 277). The estimate of such numerical relations has, at all events, this merit, notwithstanding other defects, that the assumption of a very high standard of measurement of space leads to results which may be expressed in smaller numbers.

explored, we shall be vividly impressed with the idea that the solar system, especially in the great mutual connection revealed to us during the last ten years, yields the richest image of the evident and direct relations borne by many cosmical bodies to a special one.

The more limited sphere of the planetary system affords by its very limitation undoubted advantages, both as to the certainty and correctness of the facts ascertained by measuring and calculating astronomy, over the results of a contemplation of the heaven of the fixed stars. Many of these results are only connected with contemplative astronomy, through the medium of stellar swarms and nebulous groups, as well as of the insecurely-based photometric arrangement of the stars. The most certain and brilliant portion of astrognosy is the determination of positions by right ascension and declination,—a department of astronomical science that has been very extensively improved and increased in our own day, in reference to isolated fixed stars, double stars, stellar masses, and nebulæ. Equally difficult, although more or less accurately measureable relations likewise present themselves in the proper motion of the stars—the elements from which their parallaxes are determined—telescopic star-gauging which leads us to the distribution in space of cosmical bodies—the periods of variable stars—and the slow revolution of double stars. That which from its very nature is not amenable to measurement, such as the relative position and configuration of starry strata or rings of stars, the arrangement of the universe, and the effects of powerfully metamorphic physical forces[*] in the sudden appearance or extinction of the so-called new stars, excites the mind the more deeply and

[*] On the appearance of new stars, and their subsequent disappearance, see pp. 204–222.

vividly, by its touching on the confines of the graceful domain of fancy.

We purposely abstain in the following pages from entering on the consideration of the connection existing between our solar system and the systems of other fixed stars, nor shall we revert to the question of that subordination and annexation of cosmical systems which might almost be said to force itself on our notice from intellectual necessity; nor yet will we consider whether our central body, the Sun, may not itself stand in some planetary dependence on a higher system,—not even, perhaps, as a main planet, but merely as a planetary satellite, like Jupiter's moons. Limited within the more familiar sphere of our solar region, we, however, enjoy this advantage, that with the exception of what refers to the signification of the surface-appearance or gaseous envelopes of the revolving cosmical bodies, the simple or divided tails of comets, the ring of the zodiacal light, or the mysterious appearance of meteoric asteroids, almost all the results of observation admit of being referred to numerical relations, as the deductions of strictly-tested presuppositions. It does not, however, belong to the sketch of a physical description of the universe to test the accuracy of such presuppositions, its province being simply to give a methodical arrangement of numerical results. They constitute the important heritage which, ever augmenting, is bequeathed by one century to another. A table, comprising the numerical elements of the planets (that is to say, their mean distances from the Sun, sidereal periods of revolution, the excentricity of their orbits, their inclination towards the ecliptic, their diameter, mass, and density), would now embrace within very narrow limits the record of the great intellectual conquests of the present age. Let us for a moment transport ourselves in imagination to the times

of the ancients, and fancy Philolaus the Pythagorean, the instructor of Plato, Aristarchus of Samos, or Hipparchus, in possession of such a numerical table, or of a graphic representation of the orbits of the planets, such as is given in our most epitomized manuals; there is scarcely anything to which we could compare the admiration and surprise of these men,—the heroes of the early and limited knowledge of that age,—excepting, perhaps, that which might have been experienced by Eratosthenes, Strabo, and Claudius Ptolemy, could they have seen one of our maps of the world, on Mercator's projection, not above a few inches in length and breadth.

The return of comets in closed elliptical orbits, as a consequence of the attractive force of the central body, indicates the limits of the solar region. As, however, we are as yet ignorant whether comets may not some day appear in which the major axis may prove to be larger than any that have as yet been observed and calculated, these bodies must be regarded as indicating, in their aphelia, merely the limits to which the solar regions must *at least* extend. Hence we may characterize the solar system by the visible and measurable results of peculiar operating central forces, and by the cosmical bodies (planets and comets) which rotate round the Sun in closed orbits, and are intimately connected with it. The considerations which at present engage our attention, do not embrace a notice of the attraction which the Sun may exert on other suns (or fixed stars) lying beyond the limits of these re-appearing cosmical bodies.

According to the state of our knowledge at the close of this half of the nineteenth century, the solar region includes the following bodies, arranging the planets according to their respective distances from the central body:

22 PRINCIPAL PLANETS (MERCURY, VENUS, THE EARTH, MARS; *Flora, Victoria, Vesta, Iris, Metis, Hebe, Parthenope, Irene, Astræa, Egeria, Juno, Ceres, Pallas, Hygica;* JUPITER, SATURN, URANUS, NEPTUNE);

21 SATELLITES (1 belonging to the Earth, 4 to Jupiter, 8 to Saturn, 6 to Uranus, 2 to Neptune);

197 COMETS, whose orbits have been calculated. Of these 6 are *interior; i. e.* such as have their aphelia inclosed within the outermost of the planetary orbits, viz. that of Neptune: we may very probably add to these;

THE RING OF THE ZODIACAL LIGHT, which probably lies between the orbits of Venus and Mars; and likewise, according to the opinion of numerous observers:

THE SWARMS OF THE METEOR-ASTEROIDS which more especially intersect the Earth's orbit at certain points.

In the enumeration of the 22 principal planets, of which 6 only were known before the 13th of March, 1781, the 14 *small planets*, which are sometimes termed *co-planets* or *asteroids*, and describe intersecting orbits between Mars and Jupiter, have been distinguished from the 8 *larger planets* by the use of smaller type.

The following occurrences constitute *main epochs* in the more recent history of planetary discoveries. The discovery of Uranus, as the first planet beyond Saturn's orbit, by William Herschel at Bath, on the 13th of March, 1781, who recognized it by its motion and disc-like form; the discovery of Ceres—the first observed of the smaller planets—on the 1st of January, 1801, by Piazzi at Palermo; the recognition of the first interior comet by Encke at Gotha, in August, 1819; and the prediction of the existence of Neptune by Leverrier, at Paris, in August, 1846, by the calculation of planetary disturbances, as well as the discovery of Neptune

by Galle, at Berlin, on the 23rd of September, 1846. These important discoveries have not only tended directly to extend and enrich our knowledge of the solar system, but have further led to numerous other discoveries of a similar nature; as, for instance, to the knowledge of 5 other interior comets (of Biela, Faye, De Vico, Brorsen, and D'Arrest, between 1826 and 1851), and of 13 small planets, three of which, Pallas, Juno, and Vesta, were discovered from 1801 to 1807, and after an interval of fully thirty-eight years, since Hencke's fortunate and preconceived discovery of Astræa, on the 8th of December, 1845, the 9 others were discovered, in rapid succession, by Hencke, Hind, Graham, and De Gasparis, from 1845 to the middle of 1851. The attention of observers has of late been so extensively directed to the cometary world, that the orbits of 33 newly-discovered comets have been calculated during the last eleven years; hence, nearly as many as had been determined during the previous forty years of this century.

I.

THE SUN CONSIDERED AS THE CENTRAL BODY.

THE *lantern of the world* (*lucerna Mundi*), as Copernicus names the Sun,[3] enthroned in the centre,—according to Theon of Smyrna, the all-vivifying, pulsating *heart of the Universe*[4],—is the primary source of light and of radiating heat, and the generator of numerous terrestrial, electro-magnetic processes, and indeed of the greater part of the organic vital activity upon our planet, more especially that of the vegetable kingdom. In considering the expression of solar force, in its widest generality, we find that it gives rise to alterations on the surface of the Earth,—partly by gravitative attraction,—as in the ebb and flow of the ocean (if we except the share taken in the phenomenon by lunar attraction),—partly by light and heat-generating transverse vibrations of ether, as in the fructifying admixture of the aërial and aqueous envelopes of our planet, from the contact of the atmosphere with the vaporizing fluid element in seas, lakes, and rivers. The solar action operates, more-

[3] I have already, in an earlier part of this work (vol. ii. p. 688 and note) given the passage imitated from the *Somnium Scipionis*, in chap. x. of the first book *de Revolut.*

[4] "The Sun is the heart of the Universe;" *Theonis Smyrnæi, Platonici Liber de Astronomia*, ed. H. Martin, 1849, pp. 182, 298: τῆς ἐμψυχίας μέσον τὸ περὶ τὸν ἥλιον, οἱονεὶ καρδίαν ὄντα τοῦ παντός, ὅθεν φέρουσιν αὐτοῦ καὶ τὴν ψυχὴν ἀρξαμένην διὰ παντὸς ἥκειν τοῦ σώματος τεταμένην ἀπὸ τῶν περάτων. (This new edition is worthy of notice, since it completes the peripatetic views of Adrastus, and many of the Platonic dogmas of Dercyllides.)

over, by differences of heat, in exciting atmospheric and oceanic currents; the latter of which have continued for thousands of years (though in an inconsiderable degree) to accumulate or wash away alluvial strata, and thus change the surface of the inundated land; it operates in the generation and maintenance of the electro-magnetic activity of the Earth's crust, and that of the oxygen contained in the atmosphere; at one time calling forth calm and gentle forces of chemical attraction, and variously determining organic life in the endosmose of cell-walls and in the tissue of muscular and nervous fibres; at another time evoking light-processes in the atmosphere, such as the coloured coruscations of the polar light, thunder and lightning, hurricanes, and water-spouts.

Our object in endeavouring to compress in one picture the *influences of solar action*, in as far as they are independent of the orbit and the position of the axis of our globe, has been clearly to demonstrate, by an exposition of the connection existing between great, and at first-sight heterogeneous, phenomena, how physical nature may be depicted in the *History of the Cosmos* as a Whole, moved and animated by internal and frequently self-adjusting forces. But the waves of light not only exert a decomposing and re-combining action on the corporeal world; they not only call forth the tender germs of plants from the earth, generate the green colouring matter (chlorophyll) within the leaf, and give colour to the fragrant blossom—they not only produce myriads of reflected images of the Sun in the graceful play of the waves, as in the moving grass of the field—but the rays of celestial light, in the varied gradations of their intensity and duration, are also mysteriously connected with the inner life of man, his intellectual susceptibilities, and the melancholy or cheerful tone of his feelings. "*Cœli tristitiam discutit Sol et humani nubila animi serenat.*" (Plin. *Hist. Nat.* ii. 6.)

In the description of each of the cosmical bodies, I shall precede whatever consideration of their physical constitution may (except in the case of the Earth) be necessary, by their respective numerical data. The numerical arrangement of these results, is nearly identical with that which was adopted by Hansen,[1] in his admirable *Review of the Solar System*, although I have necessarily made some alterations and additions in the data, from the fact that 11 planets and 3 satellites have been discovered since 1837, the year in which Hansen wrote.

The mean distance of the centre of the Sun from the Earth is, according to Encke's supplementary correction of the Sun's parallax (*Abhandl. der Berl. Akad.* 1835, p. 309), 82,728,000 geographical miles, of which 60 go to an equatorial degree, and of which each one, according to Bessel's investigation of ten measurements of degrees (*Cosmos*, vol. i. p. 157), contains exactly 951·807 toises, or 5710·8405 Paris feet, or 6086·76 English feet.

Light requires for its passage from the Sun to the Earth *i. e.* to traverse the radius of the Earth's orbit, according to Struve's observations of aberration, 8′ 17″·78 (*Cosmos*, vol. iii. p. 110); whence it follows that the Sun's true position is about 20″·445 in advance of its apparent place.

The apparent diameter of the Sun, at its mean distance from the Earth, is 32′ 1″·8; and therefore only 54″·8 greater than the Moon's disc at its mean distance from us. In the perihelion, when in winter we are nearest to the Sun, the apparent diameter of the latter increases to 32′ 34″·6; in the aphelion, when in summer we are farthest from the Sun, its apparent diameter is diminished to 31′ 30″·1.

The Sun's true diameter is 770,800 geographical miles, or more than 112 times greater than that of the Earth.

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[1] Hansen, in Schumacher's *Jahrbuch* for 1837, pp. 65–141.

The mass of the Sun is, according to Encke's calculation of Sabine's pendulum formula, 359,551 times that of the Earth, or 355,499 times that of the Earth and Moon together (*Vierte Abhandl. über den Cometen von Pons in den Schr. der Berl. Akad.* 1842, p. 5); whence the density of the Sun is only about ¼ (or more accurately 0·252) that of the Earth.

The volume of the Sun is 600 times greater, and its mass (according to Galle) 738 times greater than that of all the planets combined. It may assist the mind in conceiving a sensuous image of the magnitude of the Sun, if we remember that if the solar sphere were entirely hollowed out, and the Earth placed in its centre, there would still be room enough for the Moon to describe its orbit, even if the radius of the latter were increased 160,000 geographical miles.

The Sun rotates on its axis in 25½ days. The equator inclines about 7° 30′ towards the ecliptic. According to Laugier's very careful observations (*Comptes rendus de l'Acad. des Sciences*, tom. xv. 1842, p. 941), the period of rotation is $25\frac{34}{100}$ days (or 25d. 8h. 9m.), and the inclination of the equator 7° 9′.

The conjectures gradually adopted in modern astronomy regarding the physical character of the Sun's surface, are based on long and careful observations of the alterations which take place in the self-luminous disc. The order of succession, and the connection of these alterations (the formation of the Sun-spots, the relation of the deep black nuclei to the surrounding ash-grey penumbræ), have led to the assumption that the body of the Sun itself is almost entirely dark, but surrounded at a considerable distance by a luminous envelope; that funnel-shaped openings are formed in this envelope, in consequence of the passage of currents from below upwards, and that the black nucleus of the spot is a portion of the dark body of the Sun which is visible through the opening. In order to render this explanation, of which

we here only briefly give the most general features, sufficiently applicable to the details of the phenomena upon the surface of the Sun, science at present assumes the existence of three envelopes round the dark solar sphere; viz. one interior cloud-like *vaporous envelope*, next a *luminous investment* (photosphere), and above these, as appears to have been especially shown by the solar eclipse of 8th of July, 1842, an *external cloudy envelope*, which is either dark, or but slightly luminous.*

* "D'après l'état actuel de nos connaissances astronomiques le Soleil se compose: 1. d'un globe central à peu près obscur; 2. d'une immense couche de nuages qui est suspendue à une certaine distance de ce globe et l'enveloppe de toutes parts; 3. d'une *photosphère;* en d'autres termes, d'une sphère resplendissante qui enveloppe la couche nuageuse, comme celle-ci, à son tour, enveloppe le noyau obscur. L'éclipse totale du 8 Juillet, 1842, nous a mis sur la trace d'une troisième enveloppe, située au-dessus de la *photosphère* et formée de nuages obscurs ou faiblement lumineux. Ce sont les *nuages* de la troisième enveloppe solaire, situés en apparence, pendant l'éclipse totale, sur le contour de l'astre ou un peu en dehors, qui ont donné lieu à ces singulières proéminences rougeâtres qui en 1842 ont si vivement excité l'attention du monde savant." "According to the present condition of our astronomical knowledge, the Sun is composed: 1st. of a central sphere which is nearly dark; 2nd. of a vast stratum of clouds, suspended at a certain distance from the central body, which it surrounds on all sides; 3rd. of a *photosphere*, or in other words, a luminous sphere inclosing the cloudy stratum, which in its turn envelopes the dark nucleus. The total eclipse of the 8th of July, 1842, afforded indications of a third envelope, situated above the *photosphere*, and formed of dark or faintly illumined clouds. These clouds of the third solar envelope, apparently situated during the total eclipse on the margin of the Sun, or even a little beyond it, gave rise to those singular, rose-coloured protuberances, which so powerfully excited the attention of the scientific

As felicitous presentiments and sports of fancy—such subsequently realized speculations as abound in Grecian antiquity—sometimes contain the germ of correct views long prior to any actual observation, so we find in the writings of Cardinal Nicolaus de Cusa (in the second book *De docta Ignorantia*), which belong to the middle of the fifteenth century, the clearly expressed opinion that the body of the Sun itself is only "an *earth-like nucleus*, surrounded by a circle of light as by a delicate envelope; that in the centre (between the dark nucleus and the luminous covering?) there is a mixture of water-charged clouds and clear air, similar to our atmosphere; and that the power of *radiating* light to vivify the vegetation of our Earth, does not appertain to the earthy nucleus of the Sun's body, but to the luminous covering by which it is enveloped." This view of the physical condition of the Sun's body, which has hitherto been but little regarded in the history of astronomy, presents considerable similarity with the opinions maintained in the present day.[7]

world in 1842."—Arago, in the *Annuaire du Bureau des Longitudes pour l'an* 1846, pp. 464, 471. Sir John Herschel, in his *Outlines of Astronomy*, p. 234, § 395 (edition of 1849), thus expresses himself: "Above the luminous surface of the Sun, and the region in which the spots reside, there are strong indications of the existence of a gaseous atmosphere, having a somewhat imperfect transparency."

[7] I would, in the first place, give in the original the passages to which I refer in the text, and to which my attention was directed by a learned work of Clemens. (*Giordano Bruno und Nicolaus von Cusa*, 1847, § 101.) Cardinal Nicolaus de Cusa (whose family name was Khrypffs, *i. e.* Crab), was born at Cues, on the Moselle. He thus writes in the twelfth chapter of the second book of the Treatise *De docta Ignorantia* (Nicolai de Cusa *Opera*, ed Basil, 1565, p. 39), a work that was much esteemed at that age: "Neque color nigredinis est argumentum vilitatis Terræ; nam in Sole si quis esset, non

The spots on the Sun, as I have already shown in the

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appareret illa claritas quæ nobis: considerato enim corpore Solis, tunc habet quandam quasi terram centraliorem, et quandam luciditatem quasi ignilem circumferentialem, et in medio quasi aqueam nubem et aërem clariorem, quemadmodum terra ista sua elementa." "Blackness of colour is no proof of the inferiority of the Earth's substance: for to an inhabitant of the Sun, if such there be, the same brilliancy of appearance would not be presented as to us: if we consider the Sun's body, we shall conclude that it consists of a certain earthy substance in the centre, surrounded by a luminous matter, partaking, perhaps, of the nature of fire, and in the midst a sort of aqueous clouds and brighter atmosphere, resembling the elements of which the Earth consists." To this are appended the words *Paradoxa* and *Hypni*: by the last of which, he probably understands (*ἐνύπνια*) certain speculations, vague and bold hypotheses. In the long Treatise, *Excercitationes ex Sermonibus Cardinalis* (*Opera*, p. 579) I again find the following comparison: "Sicut in Sole considerari potest natura corporalis, et illa de se non est magnæ virtutis" (notwithstanding the attraction of masses or gravitation!) "et non potest virtutem suam aliis corporibus communicare, quia non est radiosa. Et alia natura lucida illa unita, ita quod Sol ex unione utriusque naturæ habet virtutem quæ sufficit huic sensibili mundo, ad vitam innovandam in vegetabilibus et animalibus, in elementis et mineralibus per suam influentiam radiosam. Sic de Christo, qui est Sol justitiæ . . ." "As in the Sun may be supposed to exist a corporeal nature, which of itself is of no great efficacy, and cannot communicate its virtue to other bodies, because it is not radiant, and another nature united with this; so that the Sun, from the union of the two natures, has a virtue which suffices for this sensible world, to renew life in vegetables and animals, in elements and minerals, by its own radiant influence. So from Christ, the Sun of Justice . ."

Dr. Clemens thinks that all this must be more than a mere felicitous presentiment. It appears to him unlikely that Cusa, in the expressions "*Considerato corpore Solis*;" "*in Sole considerari potest* . . ." "could have appealed to

experience, without a tolerably accurate observation of the Sun's spots, both their darker portions and the penumbræ." He also conjectures "that the penetration of the philosopher may have been in advance of the results of the science of his age, and that his views may have been influenced by discoveries which have usually been ascribed to later observers." It is, indeed, not only possible, but even highly probable, that in districts where the Sun is obscured for many months, as on the coast of Peru, during the *garua,* even uncivilized nations may have seen Sun-spots with the naked eye; but no traveller has, as yet, afforded any evidence of such appearances having attracted attention, or having been incorporated among the religious myths of their system of Sun-worship. The mere observation of the rare phenomenon of a Sun-spot, when seen by the naked eye, in the low, or faintly obscured, white, red, or perhaps greenish disc of the Sun, would scarcely have led even experienced observers to conjecture the existence of several envelopes around the dark body of the Sun. Had Cardinal de Cusa known anything of the spots of the Sun, he would assuredly not have failed to refer to these *maculæ Solis* in the many comparisons of physical and spiritual things in which he was too much inclined to indulge. We need only recall the excitement and bitter contention with which the discoveries of Joh. Fabricius and Galileo were received, soon after the invention of the telescope in the beginning of the seventeenth century. I have already referred (*Cosmos*, vol. ii. p. 692) to the obscurely expressed astronomical views of the Cardinal, who died in 1464, and therefore nine years before the birth of Copernicus. The remarkable passage: "Jam nobis manifestum est Terram in veritate moveri;" "Now it is evident that the Earth really moves," occurs in lib. ii. cap. 12, *De docta Ignorantia.* According to Cusa, *motion* pervades every portion of the celestial regions; we do not even find a star that does not describe a circle. "Terra non potest esse fixa, sed movetur ut aliæ stellæ;" "The Earth cannot be fixed, but moves like other stars." The Earth, however, does not revolve round the Sun, but the Earth and the Sun rotate

Universe,[8] were not first observed by Galileo, Scheiner, or Harriot, but by John Fabricius of East Friesland, who also was the first to describe, in a printed work, the phenomenon he had seen. Both this discoverer and Galileo, as may be seen by his letter to the Principe Cesi (25th of May, 1612), were aware that the spots belonged to the body of the Sun itself; but ten or twenty years later, Jean Tarde, a canon of Sarlat, and a Belgian Jesuit, maintained almost simultaneously that the Sun's spots were the transits of small planets. The one named them *Sidera Borbonia*, the other, *Sidera Austriaca*.[9] Scheiner was the first who employed blue and green

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"around the ever-changing pole of the Universe." Cusa did not, therefore, hold the Copernican views, as has been so successfully shown by Dr. Clemens' discovery in the hospital at Cues, of the fragmentary notice written in the Cardinal's own hand in 1444.

[8] *Cosmos*, vol. ii. pp. 706–708.

[9] *Borbonia Sidera*, id est, planetæ qui Solis lumina circumvolitant motu proprio et regulari, falso hactenus ab helioscopis maculæ Solis nuncupati, ex novis observationibus. Joannis Tarde, 1620. *Austriaca Sidera* heliocyclica astronomicis hypothesibus illigata opera Caroli Malapertii Belgæ Montensis e Societate Jesu, 1633. The latter work has at all events the merit of affording observations of a succession of spots between 1618 and 1626. This period includes the years for which Scheiner published his own observations at Rome in his *Rosa Ursina*.. The Canon Tarde believes those appearances to be the transits of small planets, because "l'œil du monde ne peut avoir des ophthalmies," "the eye of the universe cannot experience ophthalmia." It must justly excite surprise, that the meritorious observer, Gascoigne (see p. 79) should twenty years after Tarde's notice of the Borbonic satellites, still have ascribed the Sun's spots to a conjunction of numerous planetary bodies revolving round the Sun in close proximity to it and in almost intersecting orbits. Several of these bodies, placed, as it were, one over another, were supposed to occasion the black shadows. (*Philos.*

stained glasses in solar observations, which had been proposed seventy years earlier by Apian (Bienewitz), in the *Astronomicum Cæsareum*, and had also been long in use among Belgian pilots.[10] The neglect of this precaution contributed much to Galileo's blindness.

As far as I am aware, the most definite expression of the necessity for assuming the existence of a dark solar sphere, surrounded by a photosphere, grounded upon direct observation after the discovery of the Sun's spots, is first to be met with in the writings of the great Dominique Cassini,[11] and belongs probably to about the year 1671. According to his views, the solar disc which we see is "an ocean of light surrounding the solid and dark nucleus of the Sun; the violent movements (*up-wellings*) which occur in this luminous enve-

Transact. vol. xxvii. 1710–1712, pp. 282–290, from a letter of William Crabtree, August, 1640.)

[10] Arago, *Sur les moyens d'observer les taches solaires,* in the *Annuaire pour l'an* 1842, pp. 476–479. Delambre, *Hist. de l'Astronomie du moyen âge*, p. 394; and his *Hist. de l'Astronomie moderne*, tom. i. p. 681.

[11] *Mémoires pour servir à l'Histoire des Sciences*, par M. le Comte de Cassini, 1810, p. 242; Delambre, *Hist. de l'Astr. mod.* tom. iii. p. 694. Although Cassini in 1671, and La Hire in 1700, had declared the Sun's body to be dark, otherwise trustworthy and valuable text-books on astronomy still continue to ascribe the first idea of this hypothesis to the meritorious Lalande. Lalande, in the edition of 1792, of his *Astronomie*, tom. iii. § 3240, as in the first edition of 1764, tom. ii. § 2,515, merely adopts the older view of La Hire, according to which "les taches sont les éminences de la masse solide et opaque du Soleil, recouverte communément (en entier) par le fluide igné;" "the spots are the elevations of the solid and opaque mass of the Sun, covered by an igneous fluid." Alexander Wilson, between the years 1769 and 1774, conceived the first correct view of a funnel-shaped opening in the photosphere.

lope enable us from time to time to see the mountain summits of the non-luminous body of the Sun. These constitute the *black nuclei* in the centre of the Sun's spots." The ash-coloured penumbræ surrounding these nuclei had not then been explained.

An ingenious observation, which has subsequently been fully confirmed, made by the astronomer, Alexander Wilson of Glasgow, of a large solar spot, on the 22nd of November, 1769, led him to an elucidation of the penumbræ. Wilson discovered that as a spot moved towards the Sun's margin, the penumbra became gradually more and more narrow on the side turned towards the centre of the Sun, compared with the opposite side. The observer, in 1774, very correctly concluded,[13] from these relations of dimension, that the nucleus of the spot (the portion of the dark solar body visible through the funnel-shaped excavation in the luminous envelope) was situated at a greater depth than the penumbra, and that the latter was formed by the shelving lateral walls of the funnel. This mode of explanation did not, however, solve the question why the penumbræ were the lightest near the nuclei.

The Berlin astronomer, Bode, in his work entitled "Thoughts on the Nature of the Sun, and the Formation of its Spots" (*Gedanken über die Natur der Sonne und die*

[13] Alexander Wilson, *Observations on the Solar Spots*, writes as follows in the *Philos. Transact.* vol. lxiv. 1774, part i. pp. 6–13, tab. i.:—"I found that the umbra, which before was equally broad all round the nucleus, appeared much contracted *on that part which lay towards the centre of the disc*, whilst the other parts of it remained nearly of the former dimensions. I perceived that the shady zone or umbra, which surrounded the nucleus, might be nothing else but the shelving sides of the luminous matter of the Sun." Compare also Arago, in the *Annuaire pour* 1842, p. 506.

Entstehung ihrer Flecken), developed very similar views with his usual perspicuity, although he was unacquainted with Wilson's earlier treatise. He moreover had the merit of having facilitated the explanation of the penumbræ, by assuming, very much in accordance with the conjectures of Cardinal Nicolaus de Cusa. the existence of another cloudy stratum of vapour between the photosphere and the dark solar body, This hypothesis of two strata leads to the following conclusions:—If there occur in less frequent cases an opening in the photosphere alone, and not at the same time in the less transparent lower vaporous stratum, which is but faintly illumined by the photosphere, it must reflect a very inconsiderable degree of light towards the inhabitants of the Earth, and a grey penumbra will be formed—a mere halo without a nucleus; but when, owing to tumultuous meteorological processes on the surface of the Sun, the opening extends simultaneously through both the luminous and the cloudy envelopes, a nucleoid spot will appear in the ash-grey penumbra, "which will exhibit more or less blackness, according as the opening occurs opposite to a sandy, rocky, or aqueous portion of the surface of the Sun's disc." [18] The halo surrounding the nucleus is further a portion of the outer surface of the vaporous stratum; and as this is less opened than the photosphere, owing to the funnel-shaped form of the whole excavation, the direction of the passage of the rays of light, impinging on both sides on the margins of the interrupted envelope, and reaching the eyes of the observer, occasions the difference, first noticed by Wilson, in the breadth of the opposite sides of the penumbra, which appears after the nucleoid spot has moved away from the

[18] Bode, in the *Beschäftigungen der Berlinischen Gesellschaft Naturforschender Freunde*, Bd. ii. 1776, pp. 237–241, 249.

centre of the Sun's disc. If, as Laugier has frequently remarked, the penumbra passes over the black nucleus causing it wholly to disappear, this obscuration must depend on the closing of the opening—not of the photosphere—but of the vaporous stratum below it.

A solar spot, which was visible to the naked eye in the year 1779, fortunately directed William Herschel's superior powers of observation and induction to the subject which we have been considering. We possess the results of his great work, which treats of the minutest particulars of the question in a very definite manner, and in a nomenclature established by himself. His observations appeared in the *Philosophical Transactions* for 1795 and for 1801. As usual, this great observer pursued his own course independently of others, referring only in one instance to Alexander Wilson. In their general character, his views may be regarded as identical with those of Bode, and he bases the visibility and dimensions of the nucleus and the penumbra (*Philos. Transact.* 1801, pp. 270, 318, tab. xviii. fig. 2), on the assumption of an opening in two envelopes, while he assumes the existence of a clear and transparent aërial atmosphere (p. 302) between the vaporous envelope and the dark body of the Sun, in which clouds that are either wholly dark, or only faintly illumined by reflection, are suspended at a height of about 280 to 320 geographical miles. William Herschel seems, in fact, also disposed to regard the photosphere as a mere stratum of *unconnected* phosphorescent clouds of very unequal surface. According to his view, "an elastic fluid of unknown nature rises from the crust or surface of the dark solar body, generating only small luminous pores in the higher regions where the action is weak, and large openings, with nuclei, surrounded by *shallows* or penumbræ, where the action is more tumultuous."*

The black spots, which are seldom round, almost always

angularly broken, and characterized by entering angles, are frequently surrounded by halos or penumbræ, which exhibit the same figure on a larger scale. There is no appearance of a transition of the colour of the spot into the penumbra, or of the latter, which is sometimes filamenttous, into that of the photosphere. Capocci and Pastorff (of Buchholz in Brandenburg)—most diligent observers—have both given very accurate representations of the angular form of the nuclei. (Schum. *Astr. Nachr.* No. 115, p. 316; No. 133, p. 291; No. 144, p. 471.) William Herschel and Schwabe saw the nucleoid spots divided by bright veins, or luminous bridges,—phenomena of a cloud-like nature generated within the second stratum where the penumbræ originate.—These singular configurations, which probably owe their origin to ascending currents, the tumultuous formation of spots, solar faculæ, furrows, and projecting stripes (*crests of luminous waves*) indicate, according to Sir William Herschel, an intense evolution of light; whilst, on the other hand, according to the same great authority, "the absence of solar spots and their concomitant phenomena seems to indicate a low degree of combustion, and, consequently, a less beneficial action on the temperature of our planet, and the development of vegetation." These conjectures led Sir William Herschel to institute a series of comparisons between the prices of corn, and the complaints of poor crops,[14] and *the absence of solar spots*, between the years 1676 and 1684 (according to Flamstead), from 1686 to 1688 (according to Dominique Cassini), from 1695 to 1700, and from 1795 to 1800. Unfortunately, however, we can never attain a knowledge of the numerical elements on which to found even a conjectural solution of such a problem; not only, as this circumspect

[14] William Herschel, in the *Philosophical Transactions of the Royal Society* for 1801, part ii. pp. 310–316.

astronomer has himself observed, because the price of corn in one part of Europe cannot be taken as a criterion of the state of vegetation over the whole continent; but more especially because a diminution of the mean annual temperature, even if it affected the whole of Europe, would afford no evidence that the Earth had derived a smaller quantity of solar heat throughout that year. It appears from Dove's investigations of the irregular variations of temperature, that extremes of meteorological conditions always lie *laterally* by one another, *i. e.* in almost equal degrees of latitude. Our own continent, and the temperate parts of North America, generally present such contrasts of temperature. When our winters are severe, the season there is mild, and conversely. These compensations in the local distribution of heat, when associated with vicinity to the ocean, are attended by the most beneficial results to mankind, owing to the indubitable influence exercised by the mean quantity of summer-heat on the development of vegetation, and consequently on the ripening of the cereals.

While William Herschel attributed an increase of heat on the Earth to the activity of the central body,—a process from which result spots on the Sun,—Batista Baliani, almost two and a half centuries earlier, in a letter to Galileo, described solar spots as cooling agents.[15] This opinion coincides with

[15] We find a reference in the historical fragments of the elder Cato to an official notice of the high price of corn, and an obscuration of the Sun's disc, which continued for many months. The "*luminis caligo*," and "*defectus Solis*," of Roman authors, does not invariably indicate an eclipse of the Sun; as, for instance, in the account of the long-continued diminution of the Sun's light after the death of Cæsar. Thus, for instance, we read in Aulus Gellius, *Noct. Att.* ii. 28, "Verba Catonis in Originum quarto hæc sunt: non libet scribere, quod in tabula apud Pontificem maximum est,

the experiment made by the zealous astronomer Gautier[16] at Geneva, in comparing four periods characterized by numerous and by few spots on the Sun's disc (from 1827 to 1843), with the mean temperatures presented by thirty-three European and twenty-nine American stations of similar latitude. This comparison proves, by positive and negative differences, the contrasts exhibited by opposite Atlantic coasts. The final results, however, scarcely give 0·76° Fahr. as the cooling force ascribed to the Sun's spots, and this might with equal propriety be attributed to errors of observation and the direction of the winds at the localities indicated.

It still remains for us to notice the *third envelope* of the Sun, to which we have already referred. This is the most external of the three; inclosing the photosphere, is cloudy, and of imperfect transparency. The remarkable phenomena of red, mountain, or flame-like elevations, which, if not seen for the first time, were at all events more distinctly visible during the eclipse of the Sun of the 8th of July, 1842, when they were simultaneously noticed by several of the most experienced observers, have led astronomers to assume the existence of a third envelope of this kind. Arago, in a treatise devoted to the subject,[17] has with much ingenuity tested the several observations, and enumerated the grounds which necessitated the adoption of this view. He has at the same time shown

quotiens anona cara, quotiens Lunæ an Solis lumini caligo, aut quid obstiterit." "The words of Cato in the fourth book of his *Origines* are these: I may not write what is frequently entered in the tables of the priests, that corn was dear whenever there was any decrease in the light of the Sun and Moon, or when anything obscured them."

[16] Gautier, *Recherches relatives à l'influence que le nombre des taches solaires exerce sur les températures terrestres*, in the *Bibliothèque Universelle de Genève*, Nouv. Série, tom. li. 1844, pp. 327–335.

[17] Arago, in the *Annuaire pour* 1846, pp. 271–438.

that since 1706 similar red marginal protuberances have been eight times described on the occasion of total or annular solar eclipses.[18] On the 8th of July, 1842, when the apparently larger disc of the Moon entirely covered the Sun, the Moon's disc was observed to be surrounded not only by a whitish light,[19] encircling it like a crown or luminous wreath, but two or three protuberances were also seen, as if originating at its margin, and were compared by some observers to red jagged mountains, by others to reddened masses of ice, and again by others to fixed indented red flames. Arago, Laugier, and Mauvais at Perpignan, Petit at Montpelier, Airy on the Superga, Schumacher at Vienna, and numerous other astronomers, agreed perfectly in the main features of the final results, notwithstanding the great differences in the instruments they employed. The elevations did not always appear simultaneously; in some places they were even seen by the naked eye. The estimates of the angles of altitude certainly differed; the most reliable is probably that of Petit, the director of the observatory at Toulouse. He fixed it at 1′ 45″, which, if these phenomena were true *sun-mountains*, would give an elevation of 40,000 geographical miles; that is to say, nearly seven times the Earth's diameter, which is only 112th part of the diameter of the Sun. The consideration of these phenomena has led to the very probable hypothesis, that these red figures are emanations within the third envelope,—*clouds*, which are illuminated and coloured by the

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[18] Arago, in the *Annuaire pour* 1846, pp. 440–447.

[19] This is the white appearance which was also observed in the solar eclipse of the 15th of May, 1836, and which the great astronomer of Königsberg very correctly described at the time by observing "that although the Moon's disc entirely covered the Sun, a luminous corona still encircled it, which was a portion of the Sun's atmosphere." (Bessel, in Schum. *Astr. Nachr.* No. 320.

photosphere.[20] Arago, in putting forward this hypothesis, expresses the conjecture that the intense blue colour of the sky, which I have myself measured upon the loftiest part of the Cordilleras, though with instruments which are certainly still very imperfect, may afford a convenient opportunity for frequently observing these mountain-like clouds in the outermost atmosphere of the Sun.[21]

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[20] "Si nous examinions de plus près l'explication d'après laquelle les protubérances rougeâtres seraient assimilées à des nuages (de la troisième enveloppe), nous ne trouverions aucun principe de physique qui nous empêchât d'admettre que des masses nuageuses de 25.000 à 30,000 lieues de long flottent dans l'atmosphère du Soleil; que ces masses, comme certains nuages de l'atmosphère terrestre, ont des contours arrêtés, qu'elles affectent, ça et là, des formes très tourmentées, même des forms en surplomb; que la lumière solaire (la photosphère) les colore en rouge. Si cette troisième enveloppe existe, elle donnera peutêtre la clef de quelques-unes des grandes et déplorables anomalies que l'on remarque dans le cours des saisons."—"On examining more closely the grounds on which these rose-coloured protuberances are compared to clouds (of the third atmosphere) we do not find any principle in physics which would oppose the assumption that masses of clouds extending from 25,000 to 30,000 leagues, float in the Sun's atmosphere; that these masses, like some clouds in our terrestrial atmosphere, assume contours exhibiting here and there much-involved forms, appearing sometimes even sloping or inverted, as it were; and that they are coloured red by the light of the Sun (the photosphere). If this third atmosphere actually exist, it may, perhaps, tend to solve some of those vast and deplorable anomalies which we observe in the course of the seasons." (Arago, in the *Annuaire pour* 1846, pp. 460, 467.)

[21] "Tout ce qui affaiblira sensiblement l'intensité éclairante de la portion de l'atmosphère terrestre qui paraît entourer et toucher le contour circulaire du Soleil, pourra contribuer à rendre les proéminences rougeâtres visibles. Il est donc permis d'espérer qu'un astronome exercé, établi au sommet

When we consider the zone in which solar spots are most commonly observed (it is only on the 8th of June and the 9th of December, that the spots describe straight lines on the Sun's disc, which at the same time are parallel with one another and the Sun's equator, and not concave or convex), we are struck by the fact, that they have rarely been seen in the equatorial region between 3° North and 3° South Latitude, and that they do not occur at all in the polar regions. They are, on the whole, most frequent in the region between 11° and 15° north of the equator; and generally of more common occurrence in the northern hemisphere, or as Sömmering maintains, may be seen there at a greater distance from the equatorial regions, than in the southern hemisphere. (*Outlines*, § 393; *Observations at the Cape*, p. 433.) Galileo even estimated the extreme limits of northern and southern heliocentric latitude at 29°. Sir John Herschel extends them to 35°, as has also been done by Schwabe. (*Schum. Astr. Nachr.* No. 473.) Laugier found some spots as high as 41° (*Comptes rendus*, tom. xv. p. 944), and Schwabe even in 50°. The spot

d'une très haute montagne, pourrait y observer régulièrement les *nuages de la troisième enveloppe solaire*, situés, en apparence, sur le contour de l'astre *ou un peu en dehors;* déterminer ce qu'ils ont de permanent et de variable, noter les périodes de disparition et de réapparition . . . . . ." "Whatever will perceptibly diminish the brilliant intensity of that portion of the terrestrial atmosphere which appears to enclose and touch the circumference of the Sun, may contribute to render the rose-coloured protuberances visible. We may, therefore, hope that an experienced astronomer may succeed, on the summit of some high mountain, in making systematic and regular observations of the *clouds of the third solar envelope*, which appear to be situated on the margin of the Sun, *or a little beyond it;* and thus determine the permanence or variability of their character, and note the epochs of their disappearance and re-appearance . . ." (Arago, *Annuaire pour* 1846, p. 471.)

observed by La Hire in 70° North Latitude, must be regarded as a very rare phenomenon.

This distribution of spots on the Sun's disc, their *rarity under the equator* and in the polar regions, and their parallel position in reference to the equator, led Sir John Herschel to the conjecture, that the obstructions which the third vaporous external atmosphere may present at some points to the liberation of heat, generates currents in the Sun's atmosphere from the poles towards the equator, similar to those which upon the Earth occasion the trade-winds and calms near the equator, owing to differences of velocity in each of the parallel zones. Some spots are of so permanent a character, that they have continued to appear for fully six months, as was the case with the large spot visible in 1779. Schwabe was enabled to follow the same group eight times in the year 1840. A black nucleoid spot, delineated in Sir John Herschel's *Observations at the Cape* (to which I have made such constant reference), was found by accurate measurement to be so large, that supposing the whole of our Earth to be propelled through the opening of the photosphere, there would still have remained a free space on either side of more than 920 geographical miles. Sömmering directs attention to the fact, that there are certain meridian belts on the Sun's disc, in which he had never observed a solar-spot for many years together. (*Thilo. de Solis maculis a Sœmmeringio observatis*, 1828, p. 22.) The great differences presented in the data given for the period of revolution of the Sun, are not, by any means, to be ascribed solely to want of accuracy in the observations; they depend upon the property exhibited by some spots, of changing their position on the disc. Laugier has devoted special attention to this subject, and has observed spots which would give separate rotations of 24d. 28m. and 26d. 46m. Our knowledge of the actual period of the rotation of the Sun, can therefore only be regarded as the *mean*

of a large number of observations of those maculæ, which, from their permanence of form, and invariability of position in reference to other co-existent spots, may form the basis of reliable observations.

Although solar maculæ may be more frequently seen by the naked eye than is generally supposed, if the Sun's disc be attentively observed, there yet occur not more than two or three notices of this phenomenon between the beginning of the ninth and of the seventeenth centuries, on the accuracy of which we can rely. Among these I would reckon the supposed retention of Mercury within the Sun's disc for eight days, in the year 807, as recorded in the annals of the Frankish kings, first ascribed to an astronomer of the Benedictine order, and subsequently to Eginhard; the 91-days transit of Venus over the Sun, under the Caliph Al-Motassem, in the year 840; and the *Signa in Sole* of the year 1096, as noticed in the *Staindelii Chronicon*. I have during several years made the epochs of the mysterious obscurations of the Sun which have been recorded in history,—or, to use a more correct expression, the periods of the more or less prolonged diminution of bright daylight — the subject of special investigation, both in a meteorological and a cosmical point of view.[22] Since large numbers of solar spots (Hevelius

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[22] Although it cannot be doubted that individual Greeks and Romans may have seen large Sun-spots with the naked eye, it is, at all events, certain, that such observations have never been referred to in any of the works of Greek and Roman authors that have come down to us. The passages of Theophrastus, *De Signis*, iv. 1, p. 797; of Aratus, *Diosem.* v. 90–92; and of Proclus, *Paraphr.* 11, 14, in which the younger Ideler (*Meteorol. Veterum*, p. 201, and in the Commentary to *Aristot. Meteor.* tom. i. p. 374) thought he could discover references to the Sun's spots, merely imply that the Sun's disc, which indicates fine weather, exhibits no difference on its surface, nothing remarkable (μηδέ τι σῆμα φέροι), but,

observed a group of this kind on the 20th of July, 1643, which covered the third part of the Sun's disc) have always been accompanied by numerous faculæ, I am not much disposed to

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on the contrary, perfect uniformity. The σῆμα, the dappled surface, is expressly ascribed to light clouds, the atmosphere (the scholiast of Arastus says, to the thickness of the air); hence we always hear of the morning and evening Sun, because their disc, independently of all Sun-spots, are supposed, even in the present day, according to an old belief, not wholly unworthy of regard, to give notice to the farmer and the mariner, as *diaphanometera*, of coming changes of weather. The Sun's disc, on the horizon, gives an indication of the condition of the lower atmospheric strata which are nearer the Earth. The first of the Sun-spots noticed in the text as visible to the naked eye, and falsely regarded in the years 807 and 840 as transits of Mercury and Venus, is recorded in the great historical collection of Justus Reuberus, *Veteres Scriptores* (1726), in the section *Annales Regum Francorum Pipini, Karoli Magni et Ludovici, a quodam ejus ætatis Astronomo, Ludovici regis domestico, conscripti*, p. 58. These annals were originally ascribed to a Benedictine monk (p. 28); but, subsequently, and correctly, to the celebrated Eginhard, Charlemagne's secretary.—See *Annales Einhardi*, in Pertz, *Monumenta Germaniæ historica*, Script. tom. i. p. 194. The following is the passage referred to: "DCCCCVII. Stella Mercurii xvi kal. April, visa est in Sole qualis parva macula nigra, paululum superius medio centro ejusdem sideris, *quæ a nobis* octo dies conspicata est; sed quando primum intravit vel exivit, nubibus impedientibus, minime notare potuimus." "On the 15th of March, DCCCCVII., Mercury appeared to be a small black spot on the Sun, a little above his centre, and was visible to us in that position for eight days; but, owing to the obstruction offered by the clouds, we were not able to see either when it reached or left that place."—The so-called transit of Venus, recorded by the Arabian astronomers, is noticed by Simon Assemanus, in the Introduction to the *Globus Cœlestis Cufico-Arabicus* Veliterni Musei Borgiani, 1790, p. xxxviii: "Anno Hegyræ 225, regnante Almootasemo Chalifa, visa est in Sole prope medium

ascribe to nucleoid spots those obscurations during which stars were partly visible, as in total solar eclipses.

As, according to Du Séjour's calculation, the longest pos-

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nigra quædam macula, idque feria tertia die decima nona mensis Regebi . . . ." This appearance was believed to be the planet Venus, and the same *black spot* (macula nigra) was supposed to have been seen for 91 days (probably with intermissions of twelve or thirteen days?). Soon after this, the reigning Chalif Motassem died.—I have selected the following seventeen examples from a large number of facts collected from the historical records derived from popular tradition, as to the occurrence of a sudden decrease in the light of the Sun:

45 B.C. At the death of Julius Cæsar: after which event the Sun remained pale for a whole year, and gave less than its usual warmth; on which account the air was thick, cold, and hazy, and fruit did not ripen.—Plutarch, in *Jul. Cæs.* cap. 87; *Dio Cass.* xliv.; Virg. *Georg.* i. 466.

33 A.D. The year of the Crucifixion. "Now from the sixth hour there was darkness over all the land till the ninth hour." (St. Matthew, xxvii. 45.) According to St. Luke, xxiii. 45, "the Sun was darkened." In order to explain and corroborate these narrations, Eusebius brings forward an eclipse of the Sun in the 202nd Olympiad, which had been noticed by the chronicler, Phlegon of Tralles. (Ideler, *Handbuch der mathem. Chronologie*, Bd. ii. p. 417.) Wurm has, however, shown that the eclipse which occurred during this Olympiad, and was visible over the whole of Asia Minor, must have happened as early as the 24th of November, 29 A.D. The day of the Crucifixion corresponded with the Jewish Passover (*Ideler*, Bd. i. pp. 515–520), on the 14th of the month Nisan, and the Passover was always celebrated at the time of the *full moon*. The Sun cannot therefore have been darkened for three hours by the Moon. The Jesuit Scheiner thinks the decrease in the light might be ascribed to the occurrence of large Sun-spots.

sible duration of a total eclipse of the Sun cannot be more than 7m. 58s. at the equator, nor more than 6m. 10s. for the latitude of Paris; the decrease of daylight which is recorded

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358 A.D. A darkening continuing two hours, on the 22nd of August, *before* the fearful earthquake of Nicomedia, which also destroyed several other cities of Macedonia and Pontus. The darkness continued from two to three hours: "nec contigua vel adposita cernebantur." "Without either contiguous objects or those in juxtaposition being discernible."—*Ammian. Marcell.* xvii. 7.

360 A.D. In all the eastern provinces of the Roman Empire, "per Eoos tractus," there was obscurity from early dawn till noon; "Caligo a primo auroræ exortu adusque meridiem," *Ammian. Marcell.* xx. 3; but the stars continued to shine: consequently, there could not have been any shower of ashes, nor, from the *long duration* of the phenomenon, could it be ascribed to the action of a total eclipse of the Sun, to which the historian refers it. "Cum lux cœlestis operiretur, e mundi conspectu penitus luce abrepta, defecisse diutius solem pavidæ mentes hominum æstimabant: primo attenuatum in lunæ corniculantis effigiem, deinde in speciem auctum semenstrem, posteaque in integrum restitutum. Quod alias non evenit ita perspicue, nisi cum post inæquales cursus intermenstruum lunæ ad idem revocatur." "When the light of heaven, suddenly and wholly concealed, was hidden from the world, trembling men thought the Sun had left them for a very long time; at first it assumed the form of a horned moon, then increased to half its proper size, and was finally restored to its integrity. But it did not appear so bright until, after all irregular motions were over, it returned." This description entirely corresponds with a true eclipse of the Sun; but how are we to explain its long duration, and the "caligo" experienced in all the provinces of the East?

409 A.D. When Alaric appeared before Rome, there was so great a darkness, that the stars were seen by day.—Schnurrer, *Chronik der Seuchen*, Th. i. p. 113.

536. Justinianus I. Cæsar imperavit annos triginta-octo

by the annalists may, on account of its duration for many hours, possibly be referred to one or other of the three following and very different causes: 1. A disturbance in the

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(727 to 565). Anno imperii nono deliquium lucis passus est Sol, quod annum integrum et duos amplius menses duravit, adeo ut parum admodum de luce ipsius appareret; dixeruntque homines Soli aliquid accidisse, quod nunquam ab eo recederet." "In the ninth year of the reign of Justinian I., who reigned thirty-eight years, the Sun suffered an eclipse, which lasted a whole year and two months, so that very little of his light was seen; men said that something had clung to the Sun, from which it would never be able to disentangle itself." —Gregorius Abu'l-Faragius, *Supplementum Historiæ Dynastiarum*, ed. Edw. Pocock, 1663, p. 94. This phenomenon appears to have been very similar to one observed in 1783, which, although it has received a name (Höhenrauch),* has in many cases not been satisfactorily explained.

567 A.D. "Justinus II. annos 13 imperavit (565–578). Anno imperii ipsius secundo apparuit in cœlo ignis flammans juxta polum arcticum, qui annum integrum permansit; obtexeruntque tenebræ mundum ab hora diei nona noctem usque, adeo ut nemo quicquam videret; deciditque ex aëre quoddam pulveri minuto et cineri simile." "In the second year of the reign of Justinian II., who reigned thirteen years, there appeared a flame of fire in the heavens, near the North Pole, and it remained there for a whole year; darkness was cast over the world from three o'clock until night, so that nothing could be seen; and something resembling dust and ashes fell down from the sky."—Abu'l-Farag. l. c. p. 95. Could this phenomenon have continued for a whole year like a perpetual northern-light (magnetic storm) and been succeeded by darkness and showers of meteoric dust?

* A kind of thick, yellowish fog, common in North Germany.

process of the evolution of light, as it were a diminution of intensity in the photosphere; 2. Obstructions (such as a greater and denser formation of clouds) in the outermost

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626 A.D. According also to Abu'l-Farag. (*Hist. Dynast.* pp. 94, 99), half of the Sun's disc continued obscured for eight months.

733 A.D. One year after the Arabs had been driven back across the Pyrenees after the battle of Tours, the Sun was so much darkened on the 19th of August, as to excite universal terror. — Schnurrer, *Chron.* theil i. p. 164.

807 A.D. A Sun-spot was observed, which was believed to be the planet Mercury.—Reuber, *Vet. Script.* p. 58 (see p. 375.)

840 A.D. From the 28th of May to the 26th of August (Assemani singularly enough gives the date of May, 839), the so-called transit of Venus across the Sun's disc was observed. (See above, pp. 379–380.) The Chalif Al-Motassem reigned from 834 to 841, when he was succeeded by Harun-el-Watek, the ninth Chalif.

934 A.D. In the valuable work *Historia de Portugal*, by Faria y Souza, 1730, p. 147, I find the following passage: "En Portugal se vió sin luz la tierra por dos meses. Avia el Sol perdido su splendor." The Earth was without light for two months in Portugal, for the Sun had lost its brightness. The heavens were then opened in fissures "por fractura," by strong flashes of lightning, when there was suddenly bright Sun-light.

1091 A.D. On the 21st of September, the Sun was darkened for three hours, and when the obscuration had ceased, the Sun's disc still retained a peculiar colour. "Fuit eclipsis Solis, 11 Kal. Octob. fere tres horas: Sol circa meridiem dire nigrescebat." Martin Crusius, *Annales Suevici*, Francof. 1595, tom. i. p. 279; Schnurrer, th. i. p. 219.

1096 A.D. Sun-spots were seen by the naked eye on the 3rd of March. "Signum in Sole apparuit V, Nono Marcii feria secunda incipientis quadragesimæ. Joh. Staindelii, Presbyteri Pataviensis, *Chronicon generale*,

opaque vaporous envelope investing the photosphere, by which the radiation of solar light and heat is impeded; 3. The impure condition of our atmosphere, arising, for

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in *Oefelii Rerum Boicarum Scriptores*, tom. i. 1763, p. 485.

1206 A.D. On the last day of February, there was, according to Joaquin de Villalba (*Epidemiologia española*, Madr. 1803, tom. i. p. 30), complete darkness for six hours, turning the day into night. This phenomenon was succeeded by long-continued and abundant rains. "El dia ultimo del mes de Febrero hubo un eclipse de Sol que duró seis horas con tanto obscuridad como si fuera media noche. Siguiéron á este fenomeno abundantes y continuas lluvias." A very similar phenomenon is recorded for June, 1191, by Schnurrer, th. i. pp. 258. 265.

1241 A.D. Five months after the Mongolian battle at Liegnitz, the Sun was darkened (in some places?) and such darkness caused that the stars could be seen in the heavens at three o'clock on Michaelmas day. "Obscuratus est Sol (in quibusdam locis?), et factæ sunt tenebræ, ita ut stellæ viderentur in cœlo, circa festum S. Michælis hora nona." *Chronicon Claustro-Neoburgense* (of the Monastery of Neuberg, at Vienna: this chronicle comprises the annals of the period from the year 218 A.D. to 1348) Pez, *Scriptores rerum Austriacarum*, Lips. 1721, tom. i. p. 458.

1547 A.D. The 23rd, 24th, and 25th of April, consequently the days preceding, and immediately succeeding the battle of Mühlbach, in which the Elector John Frederick was taken prisoner. Kepler says in *Paralipom. ad Vitellium, quibus Astronomiæ pars Optica traditur*, 1604, p. 259, "The elder and younger Gemma record that in the year 1547, before the battle between Charles V and the Duke of Saxony, the Sun appeared for three days as if it were suffused by blood, while at the same time many stars were visible at noon." "Refert Gemma, pater et filius, anno 1547, ante conflictum Caroli V cum Saxoniæ Duce, Solem per tres dies ceu

instance, from the obscuring (mostly organic) meteoric dust, ink-, or sand-rain, such as is described by Macgowan to have continued for several days together in China. The second and third of these causes do not require the occurrence of a diminution of the electro-magnetic light process, perhaps, (of the perpetual polar light[33]) in the solar atmosphere; but the last-named cause excludes the visibility of stars at noon, of which such frequent mention is made in these mysterious and vaguely described obscurations.

Arago's discovery of *chromatic polarization* has not only confirmed the existence of the third and outermost envelope of the Sun, but has likewise added considerable weight to the conjectures advanced in reference to the whole physical con-

sanguine perfusum comparuisse, ut etiam stellæ pleraque in meridie conspicerentur." Kepler, (in *Stella Nova in Serpentario*, p. 113,) further expresses his uncertainty as to the cause of the phenomenon; he asks whether the diminution of the Sun's light be owing to some celestial causes: "Solis lumen ob causas quasdam sublimes hebetari . . . ." whether it be owing to the wide diffusion of some cometary substance "materia cometica latius sparsa," for the cause cannot have originated in our atmosphere, since the stars were visible at noon." Schnurrer (*Chronik der Seuchen*, th. ii. p. 93) thinks, notwithstanding the visibility of the stars, that the phenomenon must have been the same as the so-called "Höhenrauch;" for Charles V. complained before the battle, "that the Sun was always obscured when he was about to engage with the enemy." "Semper se nebulæ densitate infestari, quoties sibi cum hoste pugnandum sit." (Lambert, *Hortens. de bello german.* lib. vi. p. 182.)

[33] Horrebow (*Basis Astronomiæ*, 1735, § 226) makes use of the same expression. Solar light, according to him, is "a *perpetual Northern-light within the Sun's atmosphere*, produced by the agency of powerful *magnetic forces*." (See Hanow, in Joh. Dan. Titius' *gemeinnützige Abhandlungen über naturliche Dinge*, 1768, p. 102.)

stitution of the central body of our planetary system. "A ray of light which reaches our eyes, after traversing many millions of miles, from the remotest regions of heaven, announces, as it were of itself, in the polariscope, whether it is reflected or refracted, whether it emanates from a solid or fluid or gaseous body; it announces even the degree of its intensity. (*Cosmos*, vol. i. p. 33, and vol. ii. p. 715.) It is essential to distinguish between natural light, as it emanates directly from the Sun, the fixed stars, or flames of gas, and is polarized by reflection from a glass-plate at an angle of 35° 25′; and that polarized light, which is radiated as such from certain substances (as ignited bodies, whether of a *solid* or *liquid* nature). The polarized light which emanates from the above-named class of bodies, very probably proceeds from their interior. As the light thus emanates from a denser body into the surrounding attenuated atmospheric strata, it is refracted on the surface; and in this process a part of the refracted ray is *reflected* back to the interior, and is converted by reflection into polarized light, whilst the other portion exhibits the properties of light polarized by *refraction*. The chromatic polariscope distinguishes the two by the opposite position of the coloured complementary images. Arago has shewn, by careful experiments extending beyond the year 1820, that an ignited solid body (for instance, a red-hot iron ball), or a luminous, fused metal, yield only ordinary light, in rays issuing in a perpendicular direction, whilst the rays which reach our eyes from the margins, under very small angles, are polarized. When this optical instrument, by which the two kinds of light could be distinguished, was applied to gas flames, there was no indication of polarization, however small were the angles at which the rays emanated. If even the light be generated in the interior of gaseous bodies, the length of way does not appear to lessen the number and

intensity of the very oblique rays in their passage through the rare media of the gas, nor does their emergence at the surface and their transition into a different medium cause polarization by refraction. Now, since the Sun does not either exhibit any trace of polarization when the light is suffered to reach the polariscope in a very oblique direction, and at small angles from the margin, it follows from this important comparison that the light shining in the Sun cannot emanate from the solid solar body, nor from any liquid substance, but must be derived from a *gaseous*, self-luminous envelope. We thus possess a material physical analysis of the photosphere.

The same instrument has, however, also led to the conclusion that the intensity of the light of the Sun is not greater in the centre of the disc than at its margins. When the two complementary coloured images of the Sun—the red and blue—are so arranged that the margin of the one image falls on the centre of the other, perfect white will be produced. If the intensity of the light were not the same in the different parts of the Sun's disc, if, for example, the centre were more luminous than the margin, then the partial covering of the images in the common segments of the blue and red disc would not exhibit a pure white, but a pale red, because the blue rays would only be able to neutralize a portion of the more numerous red rays. If, moreover, we remember that in the gaseous photosphere of the Sun, in opposition to that which occurs in solid or liquid bodies, the smallness of the angle at which the rays of light emanate, does not cause their number to diminish at the margins; and as the same angle of vision embraces a larger number of luminous points at the margins than in the centre of the disc, we could not here reckon upon that *compensation* which, were the Sun a luminous iron globe, and consequently a solid body, would take place between the opposite effects of the smallness of

the angle of radiation and the comprehension of a larger number of luminous points at the same visual angle. The self-luminous *gaseous* envelope, *i. e.*, the solar disc visible to us, must therefore (in opposition to the indications of the polariscope, which shows the margin and the centre to be of equal intensity), appear more luminous in the centre than at the margin. The cause of this discrepancy has been ascribed to the outermost and less transparent vaporous envelope surrounding the photosphere, which diminishes the light from the centre less than that of the marginal rays on its long passage through the vaporous envelope.[34] Bouguer, Laplace,

[34] Arago, in the *Mémoires des sciences mathém. et phys. de l'Institut de France*, année 1811, partie i. p. 118; Matthieu, in Delambre, *Hist. de l'Astr. au dixhuitième siècle*, pp. 351, 652. Fourrier, *Eloge de William Herschel*, in the *Mém. de l'Institut*, tom. vi. année 1823 (Par. 1827), p. lxxii. It is alike remarkable and corroborative of the great uniformity of character in the light of the Sun, whether emanating from its centre or its margins, that, according to an ingenious experiment made by Forbes, during a solar eclipse in 1836, a spectrum formed from the circumferential rays alone was identical both in reference to the number and position of the dark lines or stripes intersecting it, with the spectrum arising from the entire solar light. When, therefore, rays of certain refrangibility are wanting in solar light, they have probably not passed into the Sun's atmosphere, as Sir David Brewster conjectures, since the circumferential rays produce the same dark lines when they shine through a much thicker medium. (Forbes, in the *Comptes rendus*, tom. ii. 1836, p. 576.) I will append to this note all the facts that I collected in the year 1847, from Arago's MSS.:—

"Des phénomènes de la polarisation colorée donnent la certitude que le bord du Soleil a la même intensité de lumière que le centre ; car en plaçant dans la polariscope un segment du bord sur un segment du centre, j'obtiens (comme effet complémentaire du rouge et du bleu) un blanc pur. Dans un corps solide (dans une boule de fer chauffée au rouge) le

Airy, and Sir John Herschel, are all opposed to these views of my friend, and consider the intensity of the light weaker at the

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même angle de vision embrasse une plus grande étendue au bord qu'au centre, selon la proportion du cosinus de l'angle: mais dans la même proportion aussi, le plus grand nombre de points matériels émettent une lumière plus faible, *en raison de leur obliquité*. Le rapport de l'angle est naturellement le même pour une sphère gazeuse, mais l'obliquité ne produisant pas dans les gaz le même effet de diminution que dans les corps solides, le bord de la sphère gazeuse serait plus lumineux que le centre. Ce que nous appelons le disque lumineux du Soleil, est la photosphère gazeuse, comme je l'ai prouvé par le manque absolu de traces de polarisation sur le bord du disque. Pour expliquer donc *l'égalité d'intensité* du bord et du centre indiquée par le polariscope, il faut admettre une enveloppe extérieure, qui diminue (éteint) moins la lumière qui vient du centre que les rayons qui viennent sur le long trajet du bord à l'œil. Cette enveloppe extérieure forme la couronne blanchâtre dans les éclipses totales du Soleil. La lumière qui émane des corps solides et liquides incandescens, est partiellement polarisée quand les rayons observés forment, avec la surface de sortie, un angle d'un petit nombre de degrés; mais il n'y a aucune trace sensible de polarisation lorsqu'on regarde de la même manière dans le polariscope des gaz enflammés. Cette expérience démontre que la lumière solaire ne sort pas d'une masse solide ou liquide incandescente. La lumière ne s'engendre pas uniquement à la surface des corps; une portion naît dans leur substance même, cette substance fût-elle du platine. Ce n'est donc pas la décomposition de l'oxygène ambiant qui donne la lumière. L'émission de lumière polarisée par le fer liquide est un effet de réfraction au passage vers un moyen d'une moindre densité. Partout où il y a réfraction, il y a production d'un peu de lumière polarisée. Les gaz n'en donnent pas, parceque leurs couches n'ont pas assez de densité. La Lune, suivie pendant le cours d'une lunaison entière, offre des effets de polarisation, excepté à l'époque de la pleine Lune et des jours qui en approchent beaucoup. La lumière solaire trouve, surtout dans les premiers et derniers quartiers, à la surface,

margin than in the centre. The last named of these distinguished physicists and astronomers expresses himself as follows, in

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inégale (montagneuse) de notre satellite, des inclinaisons, d plans convenables pour produire la polarisation par réflexion.'

"The phenomena of chromatic polarisation afford evidence that the margin of the Sun has the same intensity of light as the centre; for by placing in the polariscope a segment of the margin upon a central segment, I obtain a pure white as the complementary effect of red and blue. In a solid body (as in an iron ball heated red-hot.) the same visual angle embraces a larger extent of the margin than of the centre, according to the ratio of the cosine of the angle: but in the same ratio, the greater number of the material points emit a feebler light, *in consequence of their obliquity.* The ratio of the angles is naturally the same for a gaseous sphere; but since the obliquity does not produce the same amount of diminution in gases as in solid bodies, the margin of the gaseous sphere would be more luminous than its centre. That which we term the luminous disc of the Sun is the gaseous photosphere, as I have proved by the entire absence of every trace of polarization on the margin of the d . To explain the *equality of intensity* indicated by the polariscope for the margin and the centre, we must admit the existence of an outer envelope, which diminishes (extinguishes) less of the light which comes from the centre than from the marginal rays having a longer way to traverse before they reach the eye. This outer envelope forms the whitish corona of light observed in total eclipses of the Sun. The light which emanates from solid and liquid incandescent bodies, is partially polarized when the rays observed form an angle of a few degrees with the surface from whence they emerge; but there is no sensible evidence of polarization when incandescent gases are seen in the polariscope. This experiment proves, therefore, that solar light does not emanate from a solid mass or an incandescent liquid. Light is not engendered solely on the surface of bodies; but a portion originates within the substance itself, even when the experiment is made with platinum. Light, therefore, is not produced by the decomposition of the ambient oxygen. The

reference to this question:*—"Now, granting the existence of such an atmosphere, its form, in obedience to the laws of equilibrium, must be that of an oblate spheroid, the ellipticities of whose strata differ from each other and from that of the nucleus. Consequently, the equatorial portions of this envelope must be of a thickness different from that of the polar, *density for density*, so that a different obstacle must be thereby opposed to the escape of heat from the equatorial and the polar regions of the Sun." Arago is engaged at the present moment in a series of experiments, by which he purposes to test not only his own views, but also to reduce the results of observation to accurate numerical relations.

emission of polarized light from liquid iron is an effect of refraction during its passage towards a medium of lesser density. Wherever there is refraction, a small amount of polarised light must be produced: gases do not emit polarized light, because their strata do not possess the requisite amount of density. When the Moon is followed through all its phases, it will be found to afford evidences of polarization, excepting at the full moon and the days immediately preceding and following it. It is more especially during the first and last quarters that the unequal (mountainous) surface of our satellite presents suitable inclinations for the polarization of solar light by reflection."

* Sir John Herschel, *Astron. Observ. made at the Cape of Good Hope*, § 425. p. 434; *Outlines of Astr.* § 395, p. 234. Compare Fizeau and Foucault, in the *Comptes Rendus de l'Acad. des Sciences*, tom. xviii. 1844, p. 860. It is remarkable enough that Giordano Bruno, who was burnt eight years before the invention of the telescope, and eleven years before the discovery of the spots of the Sun, should have believed in the rotation of the Sun upon its axis. He considered, on the other hand, that the centre of the Sun was less luminous than the edges. Owing to an optical deception, he believed that he saw the disc turn round, and the whirling edges expand and contract. (Jordano Bruno, par Christian Bartholmess, tom. ii. 1847, p. 367.)

A comparison between solar light and the two most intense kinds of artificial light which man has hitherto been able to produce, yields, according to the present imperfect condition of photometry, the following numerical results :—Fizeau and Foucault found, by their ingenious experiments, that Drummond's light (produced by the flame of the oxy-hydrogen lamp directed against a surface of lime) was to the light of the Sun's disc as 1 to 146. The luminous current, which in Davy's experiment was generated between two charcoal points, by means of a Bunsen's battery, having forty-six small plates, was to the light of the Sun as 1 to 4·2; but when very large plates were used, the ratio was as 1 to 2·5, and this light was, therefore, not quite three times less intense than solar light.[26] When we consider the surprise still experienced at the circumstance of Drummond's dazzling light forming a black spot when projected on the Sun's disc, we are doubly struck by the felicity with which Galileo, by a series of conclusions as early as 1612,[27] on the smallness of the distance from the Sun at which the disc of Venus was no longer visible to the naked eye, arrived at the result that the blackest nucleus of the Sun's spots was more luminous than the brightest portions of the full Moon.

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[26] Fizeau and Foucault, *Recherches sur l'intensité de la Lumière émise par le Charbon dans l'expérience de Davy* in the *Comptes Rendus*, tom. xviii. 1844, p. 753.—"The most intensely ignited solid (ignited quicklime in Lieutenant Drummond's oxy-hydrogen lamp), appear only *as black spots* on the disc of the Sun when held between it and the eye." *Outlines*, p. 36 (*Cosmos*, vol. ii. pp. 707–708.)

[27] Compare Arago's commentary on Galileo's letter to Marcus Welser, as well as his optical explanation of the influence of the diffuse reflected solar light of the atmospheric strata which covers the object seen in the sky upon the field of a telescope, as it were, with a *luminous veil*, in the *Annuaire du Bureau des Long. pour* 1842, pp. 482–487.

William Herschel, assuming the intensity of the whole light of the Sun at 1,000, estimated the average light of the penumbræ at 469, and the black nuclei at 7. According to this estimate, which is certainly very conjectural, a black nucleus would yet possess 2,000 times more light than the full Moon, since the latter, according to Bouguer, is 300,000 less bright than the Sun. The degree of illumination of the nuclei visible to us, *i. e.* of the dark body of the Sun illumined by reflection from the walls of the opened photosphere, the interior atmosphere from which the penumbræ are generated, and by the light of the strata of our terrestrial atmosphere through which we see it, has been strikingly manifested on the occasion of several transits of Mercury. When compared with the planet, whose dark side was turned towards us, the near and darkest nuclei presented a light brownish-grey appearance.[28] The admirable observer, Councillor Schwabe, of Dessau, was particularly struck by this difference of blackness between the planet and the nuclei, in the transit of Mercury on the 5th of May, 1832. On the occasion of my observing the transit of this planet in Peru, on the 9th of November, 1802, in consequence of being engaged in measuring the distances from the threads, I was unfortunately unable to make any comparison between the different intensities of the light, although Mercury's disc almost touched the nearest dark spot. Professor Henry, of Princeton, North America, had already shown, by his experiments in 1815, that the Sun's spots radiate a perceptibly less heat than those portions on which there were no spots. The images of the Sun and of a large spot were projected on a screen, and the differences of heat measured by means of a thermo-electrical apparatus.[29]

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[28] Mädler, *Astr.* p. 81.

[29] *Philos. Mag.* ser. iii. vol. xxviii. p. 230; and Poggend. *Annalen*, bd. lxviii. p. 101.

Whether rays of heat differ from rays of light, by a difference in the lengths of the transversal vibrations of ether; or whether they are identical with rays of light, but that a certain velocity in the vibrations which generates very high temperatures, is requisite to excite the impression of light in our organs, the Sun, as the main source of light and heat, must nevertheless, be able to call forth and animate magnetic forces on our planet, and more especially in the gaseous strata of our atmosphere. The early knowledge of thermo-electrical phenomena in crystallized bodies (such as tourmaline, boracite, and topaz), and Oersted's great discovery (1820) that every conducting body charged with electricity exerts a definite action on the magnetic needle during the continuation of the electrical current, afforded practical evidence of the correlation of heat, electricity, and magnetism. Basing his deductions on the idea of such an affinity, Ampère, who ascribed all magnetism to electrical currents which lie in a plane at right angles to the axes of the magnet, advanced the ingenious hypothesis that terrestrial magnetism (the magnetic charge of the Earth) was generated by electrical currents, circulating round the planet from east to west; and that the horary variations of the magnetic declination are on this account consequences of the fluctuations of heat, varying with the position of the Sun, by whose action these currents are excited. These views of Ampère have been confirmed by Seebeck's thermo-magnetic experiments, in which differences of temperature of the points of contact of a circle composed of bismuth and copper, or other heterogeneous metals, affect the magnetic needle.

Another recent and brilliant discovery of Faraday's, the notice of which has been of almost simultaneous occurrence with the printing of these pages, throws an unexpected light on the same important subject. Whilst the earlier researches of this great physicist showed that all gases are diamagnetic,

i. e. assume a direction from east to west, as bismuth and phosphorus, but that this property is most feebly exhibited in oxygen; it has been shown by his latest researches, which were begun in 1847, that oxygen alone, of all gases, like iron, assumes a position from north to south; and that oxygen gas loses a portion of its paramagnetic force by expansion and by elevation of the temperature. Since the diamagnetic activity of the other constituents of the atmosphere, such as the nitrogen and carbonic acid, are not modified by expansion or by an elevation of temperature, it only remains for us to consider the oxygen "which surrounds the whole Earth, as it were, like a large sphere of sheet-tin, and receives magnetism from it." The half of this sphere which is turned towards the Sun, is less paramagnetic than the opposite half; and as the boundaries of these halves are constantly altered by their rotation and revolution round the Sun, Faraday is inclined to refer a portion of the variations of terrestrial magnetism on the Earth's surface to these thermic relations. The assimilation thus shown by experiment to exist between a single gas (oxygen) and iron, is an important discovery of our own age,[30] which derives additional value from the fact that oxygen probably constitutes the half of all the ponderable matters that occur in accessible portions of our Earth. Without assuming magnetic poles in the Sun's body, or any special magnetic forces in the solar rays, the central body may, as a powerful source of heat, excite magnetic activity on our planet.

The attempts that have been made to prove, by means of meteorological observations prosecuted for many years at

[30] Faraday upon atmospheric magnetism, in the *Exper. Researches on Electricity*, series xxv. and xxvi. (*Philos. Transact.* for 1851, part i.) § 2774, 2780, 2881, 2892, 2968, and for the history of the investigation, § 2847.

individual spots, that one side of the Sun (for instance the side which was turned towards the Earth on the 1st of January, 1846) possesses a more intense heating power than the opposite one,[a] have not led to more reliable results than the older Greenwich observations of Maskeleyne, which were supposed to prove that the Sun had decreased in diameter.

The observations made by Councillor Schwabe, of Dessau, for reducing the periodicity of the Sun's spots to definite numerical relations, appear to have a surer foundation. No astronomer of the present day, however admirable may have been his instruments, could have devoted his attention more continuously to this subject than Schwabe, who, during the long period of twenty-four years, frequently examined the Sun's disc upwards of 300 days in the year. As his observations of the Sun's spots from 1844 to 1850 have not yet been published, I have presumed so far on our friendship as to request that he would communicate them to me, and at the same time answer a number of questions which I proposed to him. I will close this section of the *Physical Constitution of our Central Body*, with the observations with which this observer has allowed me to enrich the astronomical portion of my work.

"The numbers contained in the following table leave no doubt that, at least from the year 1826 to 1850, the occurrence of spots has been so far characterized by periods of ten years, that its maxima have fallen in the years 1828, 1837, and 1848, and its minima in the years 1833 and 1843. I have had no opportunity," says Schwabe, "of acquainting myself with the older observations in a continued series, but

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[a] Compare Nervander of Helsingfors, in the *Bulletin de la Classe Physico-Mathém. de l'Acad. de St. Pétersbourg*, tom. iii. 1845, pp. 30–32; and Buys-Ballot, of Utrecht, in Poggend. *Annalen der Physik*, vol. lxviii. 1846, pp. 205–213.

I willingly concur in the opinion that this period may itself be further characterized by variability."[*]

Year.	Groups.	Days showing no Spots.	Days of Observation
1826	118	22	277
1827	161	2	273
1828	225	0	282
1829	199	0	244
1830	190	1	217
1831	149	3	239
1832	84	49	270
1833	33	139	267
1834	51	120	273
1835	173	18	244
1836	272	0	200
1837	333	0	168
1838	282	0	202
1839	162	0	205
1840	152	3	263
1841	102	15	283
1842	68	64	307
1843	34	149	312
1844	52	111	321
1845	114	29	332
1846	157	1	314
1847	257	0	276
1848	330	0	278
1849	238	0	285
1850	186	2	308

[*] I have distinguished by inverted commas the quotations from Schwabe's manuscript communications from pp. 399–400. Only the observations of the years 1826 to 1843 have already been published in Schumacher's *Astron. Nachr.* no. 495 (Bd. xxi. 1844), p. 235.

"I observed large spots visible to the naked eye in almost all the years not characterized by the minimum; the largest appeared in 1828, 1829, 1831, 1836, 1837, 1838, 1839, 1847, 1848. I regard all spots whose diameter exceeds 50″ as large, and it is only when of such a size that they begin to be visible to even the keenest unaided sight.

"The spots are undoubtedly closely connected with the formation of faculæ, for I have often observed faculæ or 'narben' formed at the same points from whence the spots had disappeared, whilst new solar spots were also developed within the faculæ. Every spot is surrounded with a more or less bright luminous cloud. I do not think that the spots exert any influence on the annual temperature. I register the height of the barometer and thermometer three times in the course of each day, but the annual mean numbers deduced from these observations have not hitherto indicated any appreciable connection between the temperature and the number of the spots. Nor, indeed, would any importance be due to the apparent indication of such a connection in individual cases, unless the results were found to correspond with others derived from many different parts of the Earth. If the solar spots exert any slight influence on our atmosphere, my tables would, perhaps, rather tend to show that the years which exhibit *a larger number of spots*, had a *smaller number of fine days* than those exhibiting few spots." (Schum. *Astron. Nachr.* No. 638, § 221.)

"William Herschel named the brighter streaks of light which are seen only towards the Sun's circumference, *faculæ*, and the vein-like streaks visible only towards the centre of the Sun's disc, 'narben' (*Astr. Nachr.* No. 350, p. 243). I am opinion that the *faculæ* and 'narben' are both derived from the same conglobate luminous clouds, which appear more intensely bright at the circumference, but being less luminous in the centre of the Sun's disc than the surface, exhibit the

appearance of "narben." I think it preferable to designate all the brighter portions of the Sun as *luminous clouds*; dividing them, according to their form, into globate and vein-like. These luminous clouds are irregularly distributed over the Sun, and when more strongly manifested occasionally impart a *mottled* or *marbled* appearance to the disc. This is often distinctly visible over the entire circumference of the Sun, and sometimes even to its poles, but yet always most decidedly manifested in the two proper zones of the spots, even when no spots are visible in those regions. At such times these bright zones of Sun-spots vividly remind one of Jupiter's belts.

"The fainter portions lying between the vein-like luminous clouds on the general surface of the Sun are deeper indentations, and always present a shagreen-like grey, sand-like appearance, reminding the observer of a mass of uniformly-sized grains of sand. On this shagreen-like surface we may occasionally notice exceedingly small faint grey (not black) *pores*, which are further intersected by very delicate dark veins. (*Astr. Nachr.* no. 473, p. 286.) These *pores*, when present in large masses, form grey nebulous groups, constituting the penumbræ of the Sun-spots. Here the pores and black points may be seen spreading from the nucleus to the circumference of the penumbra, generally in a radiating form, which occasions the identity of configuration so frequently observed to exist between the penumbra and the nucleus."

The signification and connection of these varying phenomena can never be manifested in their entire importance to the inquiring physicist, until an uninterrupted series of representations of the Sun's spots[23] can be obtained by the aid of mechanical clock-work and photographic apparatus, as the result of prolonged observations during the many

[23] Sir John Herschel, *Observations at the Cape*, p. 434.

months of serene weather enjoyed in a tropical climate. The meteorological processes at work in the gaseous envelopes of the dark body of the Sun, are the causes which produce the phenomena termed Sun-spots and conglobate luminous clouds. It is probable that there, as in the meteorology of our own planet, the disturbances of very multifarious and complicated character depend upon such general and local causes, that it can only be by means of prolonged observations, characterized by completeness, that we can hope to solve even a portion of this still obscure problem.

II.

THE PLANETS.

GENERAL *comparative* considerations of a whole class of cosmical bodies must here precede their individual description. These considerations refer to the 22 *principal planets* and 21 *moons* [*satellites*, or *secondary planets*] which have been discovered up to the present time; not to the *planetary bodies* in general, among which the comets whose orbits have been calculated are alone tenfold more numerous. The planets possess, upon the whole, a feeble scintillation, inasmuch as they shine by the reflected light of the Sun, and their planetary light emanates from discs. (*Cosmos*, vol. iii. p. 101.) In the ash-coloured light of the Moon, as well as in the red light of its obscured disc, which is seen with great intensity between the tropics, the Sun's light undergoes, in reference to the observer upon the Earth, a twice repeated change in its direction. Attention has been already directed elsewhere[1] to the fact, that the Earth and other planets possess in themselves a feeble power of emitting light, as is specially proved by some remarkable phenomena upon that portion of Venus which is turned away from the Sun.

We shall consider the planets according to their *number*,

[1] *Cosmos*, vol. i. p. 196, and note p. 197.

the *sequence* of their discovery, their *volumes* compared either with each other, or with their *distances* from the sun; according to their relative *densities, masses, periods of rotation, degrees of eccentricity, the inclinations of their axes*, and characteristic differences *within* and *beyond* the *zone of the small planets*. In the comparative contemplation of these subjects, it is consistent with the nature of this work, to bestow especial attention upon the selection of the numerical relations, which, at the period in which these pages appear, are considered to be the most accurate, *i. e.* the results of the most recent and reliable investigations.

a. PRINCIPAL PLANETS.

1. *Number and epoch of discovery.*—Of the seven cosmical bodies which, from the most remote antiquity, have been distinguished by their constantly *varying* relative position towards each other from those which apparently maintain the same positions and distances,—the scintillating stars of the region of fixed stars [orbis inerrans]—there are only five which appear *star-like*, "quinque *stellæ* errantes;" they are Mercury, Venus, Mars, Jupiter, and Saturn. The Sun and the Moon remained almost separated from the others, since they form large discs, and also on account of the greater importance attached to them in accordance with religious myths.[3] Thus, according to Diodorus (ii. 30), the Chaldeans were acquainted with only five planets. Plato also says distinctly in the *Timæus*, where he only once mentions the planets, "Round the Earth, fixed in the centre of the Cosmos,

[3] Gesenius, in the *Hallischen Litteratur-Zeitung*, 1822, Nos. 101 and 102 (Supplement, pp. 801–812). Among the Chaldeans, the Sun and Moon were held to be the two principal deities; the five planets merely represented genii.

move the Moon, the Sun, and *five other stars*, which have received the name of *planets;* the whole, therefore, in seven revolutions."[3] In the old Pythagorean representation of the celestial system, according to Philolaus, the five planets were mentioned in a similar manner among the ten deified bodies which revolve round the central fire (the focus of the universe, ἑστία) "immediately beneath the region of fixed stars;"[4] these were succeeded by the Sun, Moon, Earth, and the ἀντίχθων (the anti-Earth). Even Ptolemy always speaks of only five planets. The enumeration of the planets in systems of seven, as Julius Firmicus distributed them among the decani,[5] as they are represented in the zodiacal circle of Bianchini (probably of the third century after Christ), examined by myself elsewhere,[6] and as they are met with in the Egyptian monuments of the time of the Cæsars, does not belong to the ancient astronomy, but to the subsequent epochs, in which astrological chimeras had become universally diffused.[7] We must not be surprised

[3] Plato, in the *Timæus*, p. 38, Steph. Davis's translation, ed. Bohn, p. 342.

[4] Böckh, *de Platonico systemate cælestium globorum et de vera indole astronomiæ Philolaicæ*, p. xvii., and the same in *Philolaus*, 1819, p. 99.

[5] Jul. Firmicus Maternus, *Astron.*, libri viii. (ed. Pruckner, Basil, 1551), lib. ii. cap. 4, of the time of Constantine the Great.

[6] Humboldt, *Monumens des peuples indigènes de l'Amérique*, vol. ii. pp. 42–49. I have already directed attention in 1812 to the analogy between the zodiac of Bianchini and that of Dendera. Compare Letronne, *Observations critiques sur les représentations zodiacales*, p. 97; and Lepsius, *Chronologie der Ægypter*, 1849, p. 80.

[7] Letronne, *Sur l'Origine du Zodiaque grec*, p. 29. Lepsius, *Chronol. der Ægypt.*, p. 83. Letronne opposes the old Chaldean origin of the planetary week on account of the number seven.

that the Moon was included in the series of the seven planets, since, with the exception of a memorable theory of attraction put forward by Anaxagoras (*Cosmos*, vol. ii. p. 690, and note 27), its more intimate connexion with the Earth was scarcely ever suspected by the ancients. On the contrary, according to an opinion respecting the system of the world which Vitruvius[8] and Martianus Capella[9] quote, without stat-

[8] Vitruv. *de Archit.* ix. 4 (ed. Rode, 1800, p. 209). Neither Vitruvius nor Martianus Capella mention the Egyptians as the originators of a system, according to which Mercury and Venus are considered as satellites of the planetary sun. The former says, "Mercurii autem et Veneris stellæ circum Solis radios, solem ipsum, uti centrum, itineribus coronantes, regressus retrorsum et retardationes faciunt." "But Mercury and Venus, which encircle in their orbits the Sun itself as a centre, retrogress and proceed slowly round its rays."

[9] Martianus Mineus Felix Capella, *De Nuptiis Philos. et Mercurii*, lib. viii. (ed. Grotii, 1599, p. 289): "For though Venus and Mercury appear to rise and set daily, yet their orbits do not, however, go round the Earth, but revolve round the Sun in a wider orbit. In fact, the centre of their orbits is in the Sun, so that they are sometimes above it . . . ." "Nam Venus Mercuriusque licet ortus occasusque quotidianos ostendant, tamen eorum circuli Terras omnino non ambiunt, sed circa Solem laxiore ambitu circulantur. Denique circulorum suorum centrum in Sole constituunt, ita ut supra ipsum aliquando . . ." As this place is written over, "Quod Tellus non sit centrum omnibus planetis," "Because the Earth is not the centre of all the planets," it may certainly, as Gassendi asserts, have had an influence upon the first views of Copernicus, more than the passages attributed to the great geometer, Apollonius of Perga. However, Copernicus only says, "Minime contemnendum arbitror, quod Martianus Capella scripsit, existimans quod Venus et Mercurius circumerrant Solem in medio existentem." "I by no means think that we should despise what Martianus Capella has written, who supposes that Venus and

ing its originator, Mercury and Venus, which we call planets, are represented as satellites of the Sun, which itself revolves round the Earth. There is as little foundation for considering such a system as this to be Egyptian,[10] as there is for con-

Mercury revolve round the Sun, which is fixed in the centre." Compare *Cosmos*, vol. ii. p. 693, and note .

[10] Henry Martin, in his *Commentary to the Timæus* (*Etudes sur le Timée de Platon*, tom. ii. pp. 129–133), appears to me to have explained very happily the passage in Macrobius respecting the *ratio Chaldæorum*, which led the praiseworthy Ideler into error (in Wolff's and Buttmann's *Museum der Alterthums-Wissenschaft*, bd. ii. s. 443, and in his *Treatise upon Eudoxus*, p. 48). Macrobius (in *Somn. Scipionis*, lib. i. cap. 19, lib. ii. cap. 3, ed. 1634, pp. 64 and 90,) says nothing of the system mentioned by Vitruvius and Martianus Capella, according to which Mercury and Venus are satellites of the Sun, which, however, itself revolves with the other planets round the Earth, which is fixed in the centre. He enumerates only the differences in the succession of the orbits of the Sun, Venus, Mercury, and the Moon, according to the views of Cicero. He says, "Ciceroni, Archimedes et Chaldæorum ratio consentit; Plato Ægyptios secutus est." "Archimedes and the system of the Chaldæans agree; Plato followed that of the Egyptians." When Cicero exclaims in the eloquent description of the whole planetary system (*Somn. Scip.*, cap. 4; Edmonds' translation, ed. Bohn, p. 294): "Hunc (Solem) ut comites consequuntur Veneris alter, alter Mercurii cursus;" "The motions of Venus and Mercury follow it (the Sun) as companions," he refers only to the proximity of the Sun's orbit and those of the two inferior planets, after he had previously enumerated the three *cursus* of Saturn, Jupiter, and Mars: all revolving round the immovable earth. The orbit of a secondary planet cannot surround that of a principal planet, and yet Macrobius says distinctly: "Ægyptiorum ratio talis est: circulus, per quem Sol discurrit, a Mercurii circulo ut inferior ambitur, illum quoque superior circulus Veneris includit." "The following

founding it with the Ptolemaic epicycles, or the system of Tycho.

The names by which the *star-like* planets of the ancients were represented, are of two kinds: names of *deities*, and *significantly* descriptive names derived from physical characters. Which part of them originally belonged to the Chaldeans, and which to the Egyptians, is so much the more difficult to determine from the sources which have hitherto been made use of, as the Greek writers present us, not with the original names employed by other nations, but only translations of these into Greek equivalents, which were more or less modified by the individuality of those writers' opinions. What knowledge the Egyptians possessed anterior to the Chaldeans, whether these latter are to be considered merely as gifted disciples of the former,[11] is a question which impinges upon the important, but obscure problem of primitive civilization of the human race, and the commencement of the development of scientific ideas upon the Nile or the Euphrates. The Egyptian names of the 36 Decans are known; but the Egyptian names of the planets, with the exception of one or two, have not been transmitted to us.[12]

It is remarkable that Plato and Aristotle employed only the names of deities for the planets which Diodorus also

is the system of the Egyptians: the circle in which the Sun moves is encompassed by the circle of Mercury, which in its turn is encircled by the larger one of Venus." The orbits are are all permanently parallel to each other mutually surrounding.

[11] Lepsius, *Chronologie der Ægypter*, th. i. p. 207.

[12] The name of the planet Mars, mutilated by Vettius Valens and Cedrenus, must, in all probability, correspond to the name Her-tosch, as Seb does to Saturn. (Lepsius, *Chronol. der Ægypt.* pp. 90 and 93.)

mentions; while at a later period, for example, in the book *De Mundo*, erroneously attributed to Aristotle, a combination of both kinds of names are met with, those of deities, and the descriptive (expressive) names: φαίνων for Saturn, στίλβων for Mercury, πυρόεις for Mars.[13] Although the name

[13] The most striking differences are met with on comparing Aristot. *Metaph.* xii. cap. 8, p. 1073, ed. Bekker with Pseudo-Aristot. *De Mundo*, cap. 2, p. 392. The planet names Phaethon, Pyrois, Hercules, Stilbon, and Juno, appear in the latter work: which points to the times of Apuleius and the Antonines, in which Chaldean astrology was already diffused over the whole Roman empire, and the terms of different nations mixed with each other. (Compare *Cosmos*, vol. ii. p. 381, and note.) Diodorus Siculus says positively that the Chaldeans first named the planets after their Babylonian deities, and that these names were thus transferred to the Greeks. Ideler (*Eudoxus*, p. 48), on the contrary, ascribes these names to the Egyptians, and grounds his argument upon the old existence on the Nile of a seven-day planetary week (*Handbuch der Chronologie*, bd. i. p. 180): an hypothesis which Lepsius has completely disproved (*Chronologie der Æg*. th. i. p. 131). I will here collate from Eratosthenes, from the editor of *Epinomis* (Philippus Opuntius?), from Gemininus, Pliny, Theon of Smyrna, Cleomedes, Achilles Tatius, Julius Firmicus, and Simplicius, the synonyms of the five oldest planets, as they have been transmitted to us chiefly through predilection for astrology:

Saturn: φαίνων, Nemesis, also called a sun by five authors (Theon. Smyrna, p. 87 and 105, Martin);
Jupiter: φαέθων, Osiris;
Mars: πυρόεις, Hercules;
Venus: ἑωσφόρος, φωσφόρος, Lucifer; ἕσπερος, Vesper; Juno, Isis;
Mercury: στίλβων, Apollo.

Achilles Tatius (*Isag. in Phaen. Arati*, cap. 17.) considers it strange "that the Egyptians, as well as the Greeks, should call the least luminous of the planets, the shining" (perhaps only

of sun was strangely enough applied to Saturn, the outermost of the then known planets, as is proved by several passages in the Commentary of Simplicius (p. 122), to the eighth

because it brought prosperity). According to Diodorus, the name refers to the opinion "that Saturn was that planet which principally and most clearly foretold the future."— Letronne, *Sur l'Origine du Zodiaque grec*, p. 33, and in the *Journal des Savants*, 1836, p. 17; compare also Carteron, *Analyse de Recherches Zodiacales*, p. 97. Names which are transmitted as equivalents from one people to another, certainly depend in many cases, in addition to their origin, upon accidental circumstances, which cannot be investigated; however, it is necessary to remark here, that etymologically, φαίνειν expresses a mere shining, a fainter evolution of light which is continuous or constant in intensity, while στίλβειν refers to an intermittent scintillating light of greater brilliancy. The descriptive names: φαίνων for the remote Saturn, στίλβων for the nearer planet Mercury, appear the more appropriate, as I have before pointed out (*Cosmos*, vol. iii. p. 95), from the circumstance that as seen by day in the great refractor of Frauenhofer, Saturn and Jupiter appear feebly luminous in comparison with the scintillating Mercury. There is, therefore, as Professor Franz remarks, a succession of increasing brilliancy indicated from Saturn (φαίνων) to Jupiter, from Jupiter (φαέθων) to the coloured glowing Mars (πυρόεις), to Venus (φωσφόρος), and to Mercury (στίλβων).

My acquaintance with the Indian name of Saturn (*'sanaistschara*) *the slowly wandering*, induced me to ask my celebrated friend Bopp, whether, upon the whole, a distinction between names of deities and descriptive names, was also to be made in the Indian planetary names, as in those of the Greeks, and probably the Chaldeans. I here insert the opinion, for which I am indebted to this great philologist, arranging the planets, however, according to their actual distances from the Sun, as the above table (commencing with the greatest distance), not as they stand in *Amarakoscha* (by Colebrooke, pp. 17 and 18). There are, in fact, among the five Sanscrit names, three descriptive ones: Saturn, Mars, and Venus.

book of the *De Cœlo* of Aristotle, in Hygin, Diodorus, and Theon of Smyrna; it certainly was only its position, and the length of its orbit, which raised it above the other planets.

"Saturn: 'sanaistschara, from 'sanais, slow, and tschara, going; also 'sauri, a name of Vishnu (derived as a patronymic from 'sûra, Grandfather of Kri,) and 'sani. The planet name 'sani-vârafor 'dies Saturni,' is radically related to the adverb 'sanais, slow. The names of the week-days derived from planets appears, however, not to have been known to Amarasinha. They are, indeed, of later introduction.

"Jupiter: Vrihaspati; or, according to an older Vedic mode of writing which Lassen follows, Brihaspati: the Lord of increase, a Vedic deity: from vrih (brih), to grow, and pati, lord.

"Mars: angaraka (from angara, burning coal); also lohitânga, the red body: from lôhita, red; and anga, body.

"Venus: a male planet, which is called sukra, *i. e.* the brilliant. Another name of this planet is daitya-guru: Teacher, guru, the Titans, Daityas.

"Mercury: Budha, not to be confounded as a planet name with Buddha, the founder of the religious sect; also Rauhinêya, the son of the nymph Rohinî, wife of the Moon (soma), on which account the planet is sometimes called saumya, a patronymic of the Sanscrit word mond. The etymological root of budha, the planet name, and buddha, the name of the saint, is budh, to know. It seems to me improbable that Wuotan (Wotan, Odin) are connected with Budha. This conjecture is founded, indeed, principally upon the external similarity of form, and upon the correspondence of the name of the day of the week, 'dies Mercurii,' with the old Saxon Wôdanes-dag, and the Indian Budha-vâra, *i. e.* Budha's day. The primitive signification of vâra is repetition, for example, in bahuvârân, many times, often; it subsequently occurs at the end of a compound word with the signification day Jacob Grimm derives the German Wuotan from the verb watan, vuot (the German waten), which signifies: meare, transmeare, cum impetu ferri, and orthographically corresponds to the Latin vadere. (*Deutsche Mythologie*, p. 120.) Wuotan, Odinn is, according to Jacob Grimm, the all-power-

The descriptive names, however old and Chaldean they may be, were not very frequently employed by the Greek and Roman writers until the time of the Cæsars. Their diffusion is connected with the influence of astrology. The planetary signs are, with the exception of the disc of the Sun and the Moon's crescent upon Egyptian monuments, of very recent origin; according to Letronne's researches[14] they would not

ful, all-penetrating being: 'qui omnia permeat,' as Lucan says of Jupiter." Compare, with reference to the Indian names of the days of the week, Budha and Buddha, and the week-days in general, the observations of my brother, in his work, *Ueber die Verbindungen zwischen Java und Indien* (Kawi sprache, bd. i. pp. 187–190).

[14] Compare Letronne, *Sur l'Amulette de Jules César et les Signes Planétaires*, in the *Revue Archéologique Année III.*, 1846, p. 261. Salmasius considered the oldest planetary sign for Jupiter to be the initial letter of Ζεύς, that of Mars a contraction of the cognomen Θούριος. The sun-disc was rendered almost unrecognizable by an oblique and triangular bundle of rays issuing from it. As the Earth was not included among the planets in any of the ancient systems, except, perhaps, the Philo-Pythagorean, Letronne considers the planetary sign of the Earth "to have come into use after the time of Copernicus." The remarkable passage in Olympiodorus, on the consecration of the metals to individual planets, is taken from Proclus, and was traced by Böckh (it is in p. 14 of the Basil edition, and at p. 30 of Schneider's edition). Compare for Olympiodorus, Aristot. *Meteor.* ed. Ideler, tom. ii. p. 163. The scholium to Pindar, (*Isthm.*) in which the metals are compared with the planets, also belongs to the new Platonic school; Lobeck (Aglaophamus in *Orph.* tom. ii. p. 936). In accordance with the same connexion of ideas, planetary signs by-and-bye became signs of the metals; indeed, some (as Mercurius, for quicksilver, the *argentum vivum* and *hydrargyrus* of Pliny) became names of metals. In the valuable collection of Greek manuscripts of the Paris Library are two manuscripts on the cabalistic, or so-called sacred art, of which one (No. 2250) men-

date further back than the tenth century. Even upon stones with Gnostic inscriptions they are not met with. Subsequent transcribers have, however, added them to Gnostic and

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tions the metals consecrated to the planets without planetary signs; the other, however, (No. 2329) which, according to the writing, is of the fifteenth century, (a kind of chemical dictionary,) combines the names of the metals with a small number of planetary signs. (Höfer, *Histoire de la Chimie*, tom. i. p. 250.) In the Paris manuscript, No. 2250, quicksilver is attributed to Mercury, and silver to the Moon, while, on the contrary, in No. 2329, quicksilver belongs to the Moon, and tin to Jupiter. Olympiodorus has ascribed the latter metal to Mercury. Thus indefinite were the mystic relations of the cosmical bodies to the metallic powers.

This is also the appropriate place to mention the planetary hours and the planetary days in the small seven-day period (the week), concerning the antiquity and diffusion of which among remote nations more correct views have only recently been established. The Egyptians had originally no short periods of seven days, but periods of ten days, similar to the week, as has been proved by Lepsius (*Chronologie der Æg.* p. 132), and as is also testified by monuments which date back to the most remote times of the erection of the large pyramids. Three such decades formed one of the twelve months of the solar year. On reading the passage in Dio Cassius (lib. xxxvii. cap. 18):—"That the custom of naming the days after the seven planets was first adopted by the Egyptians, and had, in no very long time, been communicated by them to all other nations, especially the Romans, with whom it was then already quite familiarized," it must not be forgotten that this writer lived in the later period of Alexander Severus, and that since the first irruption of the Oriental astrology under the Cæsars, and in consequence of the early and extensive commerce of so many races of people in Alexandria, it was the fashion among western nations to call everything Egyptian which appeared ancient. The seven-day week was undoubtedly the earliest and most diffused among the Semitic nations; not only among the Hebrews, but even among the nomadic Arabians long before the time of Mohammed.

alchemistic manuscripts; scarcely, in any case, to the oldest manuscripts of Greek astronomers; of Ptolemy, of Theon, or of Cleomedes. The earliest planetary signs, some of which

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I have submitted to a learned investigator of Semitic antiquities, the Oriental traveller Professor Tischendorf, at Leipsic, the question, whether, besides the Sabbath, there occur in the Old Testament any names for the individual days of the week (other than the second and the third of the *schebua*)? Whether no planetary name for any one day of the seven-day period occurred anywhere in the New Testament at a period in which it was certain that the foreign inhabitants of Palestine already pursued planetary astrology? The answer was, "There is an entire absence, not only in the Old and New Testaments, but also in the Mischna and Talmud, of any traces of names of week-days, taken from the planets. Neither is the expression, the second or third day of the *schebua* employed, and time is generally reckoned by the days of the month; the day before the Sabbath is also called the sixth day, without any further addition. The word Sabbath was also transferred to the week throughout, (Ideler, *Handbuch der Chronol.* bd. i. p. 780); consequently, the first, second, and third day of the Sabbath stand for the days of the week in the Talmud as well. The word ἑβδομάς for *schebua*, is not in the New Testament. The Talmud, which certainly extends from the second to the third century, has descriptive Hebrew names for a few planets, for the brilliant Venus and the red-coloured Mars. Among these the name of Sabbatai (literally Sabbath-star,) for Saturn, is especially remarkable; as among the Pharisaic names of the stars which Epiphanius enumerates, the name Hochab Sabbath is employed for Saturn." Has not this had an influence upon the conversion of Sabbath day into Saturn day, the "*Saturni sacra dies*" of Tibullus (*Eleg.* i. 3, 18)? Another passage in Tacitus extends the range of these relations to Saturn as a planet, and as a traditional historical personage. (Compare also Fürst, *Kultur- und Litteraturgeschichte der Juden in Asien,* 1849, p. 40).

The different luminous forms of the Moon certainly attracted the observation of hunters and herdsmen earlier than astro-

(Jupiter and Mars) originated, as Salmasius has shown, with his ordinary acuteness, from letters, were very different from ours; the present form reaches scarcely beyond the

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logical phantasms. It may, therefore, be assumed, with Ideler, that the week has originated from the length of the synodic months, the fourth part of which amounts, on the average, to $7\frac{3}{8}$ days; that, on the contrary, references to the planetary series, (the sequence of their distances from each other,) together with the planetary hours and days, belongs to an entirely different period of advanced and speculative culture.

With reference to the naming of the individual week-days after planets, and the arrangement and succession of the planets—

Saturn,	Venus,
Jupiter,	Mercury, and
Mars,	Moon,
Sun,	

situated according to the most ancient and widely diffused belief (Geminus, *Elem. Astr.* p. 4; Cicero, *Somn. Scip.* cap. 4; Firmicus, ii. 4; Edmond's translation, ed. Bohn, pp. 294–298,) between the sphere of fixed stars and the immovable earth as a central body, there have been three views put forward; one derived from musical intervals; another from the astrological names of the planetary hours; a third from the distribution of each three decans, or three planets, which are the rulers (*domini*) of these decans among the twelve signs of the zodiac. The first two hypotheses are met with in the remarkable passage of Dio Cassius, in which he endeavours to explain (lib. xxxvii. cap. 17.) why the Jews, according to their laws, celebrated the day of Saturn (our Saturday). "If," says he, "the musical interval which is called διὰ τεσσάρων, the fourth, is applied to the seven planets according to their times of revolution, and Saturn, the outermost of all, taken as the starting-point; the next, which occurs in the fourth (the Sun), then the seventh (the Moon); and in this way the planets are encountered in the same order of succes-

fifteenth century. The symbolizing habit of consecrating certain metals to the planets belongs, undoubtedly, to the new Platonic doctrines of the Alexandrian school in the fifth cen-

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sion in which their names have been applied to the week-days." A commentary upon this passage is given by Vincent, *Sur les Manuscrits grecs relatives à la Musique*, 1847, p. 138; compare also Lobeck, Aglaophamus, *in Orph.* p. 941–946). The second explanation of Dio Cassius is borrowed from the periodical series of the planetary hours. "If," he adds, "the hours of the day and the night are counted from the first (hour of the day), and this ascribed to Saturn, the following to Jupiter, the third to Mars, the fourth to the Sun, the fifth to Venus, the sixth to Mercury, the seventh to the Moon, always recommencing from the beginning; it will be found, if all the twenty-four hours are gone through, that the first hour of the following day coincides with the Sun, the first of the third with the Moon; in short, the first hour of any one day coincides with the planet after which the day is named." In the same way, Paulus Alexandrinus, an astronomical mathematician of the fourth century, calls the ruler of each week-day that planet whose name agrees with the first hour of the particular day.

These modes of explaining the names of week-days have hitherto been very generally considered as the more correct; but Letronne entertains a third explanation,—the distribution of any three planets over a sign of the zodiac,—which he considers to be the most adequate, upon the evidence of the long-neglected zodiacal circle of Bianchini, preserved in the Louvre, to which I myself directed the attention of archæologists in 1812, on account of the remarkable combination of a Greek and Kirgisch-Tartar zodiac. (Letronne, *Observ. crit. et archéol. sur l'objet des représentations zodiacales*, 1824, pp. 97–99). This distribution of planets among the 36 decans of the Dodecatomeria is precisely that which Julius Firmicus Maternus (ii. 4,) describes as "signorum decani eorumque domini." If those planets are separated, which in each of the signs are the first of the three, the succession of the planetary days in the week is obtained. (Virgo: Sun, Venus,

tury, as is ascertained from passages in Proclus (*ad Tim.* ed. Basil, p. 14,) from Olympiodorus, as well as by a late scholium to Pindar, (*Isthm.* ...), (Compare Olym-

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Mercury; Libra: Moon, Saturn, Jupiter; Scorpio: Mars, Sun, Venus; Sagittarius: Mercury..... which may here serve as an example for the first four days of the week: *Dies Solis, Lunæ, Martis, Mercurii*). As, according to Diodorus, among the Chaldeans, the number of the planets (star-like) originally amounted only to five, and not seven, all the here-mentioned combinations in which more than five planets form periodical series, appear to be not of old Chaldean origin, but much rather to date from a subsequent astrological period. (Letronne, *Sur l'origine du Zodiaque grec*, 1840, p. 29.)

With respect to the concordance of the arrangement of the planets as days of the week with their arrangement and distribution among the decans in the zodiacal circle of Bianchini, a brief explanation will, perhaps, be acceptable to some readers. If a letter is assigned to each cosmical body, in the order of succession adopted in antiquity (Saturn *a*, Jupiter *b*, Mars *c*, Sun *d*, Venus *e*, Mercury *f*, Moon *g*,) and with these seven members the following periodical series are formed:—

a b c d e f g, a b c d....

there is obtained, 1st. by passing over two members of the distribution among the decans, each of which comprises three planets (the zodiacal sign of the first one giving, in each case, its name to the week-day), the new periodical series

a d g e f b e, a d g c....

that is:—*Dies Saturni, Solis, Lunæ, Martis,* and so on; 2ndly. the same new series,—

a d g c....

obtained by the method of Dio Cassius, according to which the successive week-days take their names from the planet which rules the first hour of the day: so that alternately a member of the periodical seven-membered planet-series is to be taken, and twenty-three members to be passed over. Now, it is immaterial in the case of a periodical series,

piod. *Comment. in Aristot. Meteorol.* cap. 7, 3' in Ideler's edition of the *Metereol.* tom. ii. p. 163; also tom. i. pp. 199 and 251.)

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whether it is a certain number of members which is passed over, or whether it is this number increased by any multiple of the number of members (in this case seven) of the period. By passing over twenty-three (=3.7+2) members, according to the second method, that of the planetary hours, the same result is obtained as when the first method, that of the decans is adopted, in which only two members are to be passed over.

Attention has already been directed (Note 13) to the remarkable resemblance between the fourth day of the week, *dies Mercurii*, of the Indian Budha-vâra, and the old Saxon Wodânes-dag. (Jacob Grimm, *Deutsche Mythologie*, 1844, Bd. i. p. 844.) The identity affirmed by William Jones to exist between the founder of the Buddhist religion and the race of Odin or Wuotan, and Wotan, famous in Northern heroic tales, as well as in the history of Northern civilization, will, perhaps, gain more interest when it is called to mind that the name of Wotan is met with in a part of the new continent, as belonging to a half-mythical, half-historical personage, concerning whom I have collected a great number of notes in my work on the monuments and myths of the natives of America (*Vues des Cordillères et Monumens des peuples indigènes de l'Amérique*, tom. i. pp. 208, and 382–384; tom. ii. p. 356). This American Wotan is, according to the traditions of the natives of Chiapa and Soconusco, the grandson of the man who saved his life in a boat during the great deluge, and renewed the human race; he commenced the erection of large buildings, during which time ensued a confusion of languages, war, and dispersion of races, as in the erection of the Mexican pyramids of Cholula. His name was also transferred to the calendar of the natives of Chiapa, as was the name of Odin in the north of Germany. One of the five-day periods—four of which formed the month of the people of Chiapa and the Aztecs—was named after him. While the names and signs of the days among the Aztecs were taken from animals and plants,

Although the number of the visible planets amounted, according to the earliest limitation, to five, and subsequently, by the addition of the large discs of the Sun and Moon,

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the natives of Chiapa (properly Teochiapan,) assigned to the days of the month the names of twenty chieftains who, coming from the north, had led them so far southwards. The names of the four most heroic, Wotan or Wodan, Lambat, Been, and Chinax, commenced the small periods of five-day weeks, as did the symbols of the four elements among the Aztecs. Wotan and the other chieftains indisputably belonged to the race of the Tolteks, who invaded the country in the seventh century. Ixtlilxochitl (his Christian name was Fernando de Alva) the first historian of his people, (the Aztecs,) says distinctly, in the manuscripts which he completed as early as the beginning of the sixteenth century, that the province of Teochiapan and the whole of Guatemala were peopled by Tolteks, from one coast to the other; indeed, in the beginning of the conquest of the Spaniards, a family was still living in the village Teopixca, who boasted of being descended from Wotan. The bishop of Chiapa, Francisco Nuñez de la Vega, who presided over a provincial council in Guatemala, has in his *Preambulo de las Constituciones Dioccsanas*, collected a great deal of information respecting the American tradition of Wotan. It is also still very undecided whether the tradition of the first Scandinavian Odin (Odinn, Othinus) or Wuotan, who is said to have emigrated from the banks of the Don, has an historical foundation. (Jacob Grimm, *Deutsche Mytholo*[illegible] pp. 120–150). The identity of the American an[illegible]ian Wotan, certainly not founded on mere resembl[illegible]d, is still quite as doubtful as the identity of Wuot[illegible] and Buddha, or that of the names of the founder of [illegible] religion and the planet Budha.

The assumpti[illegible]he existence of a seven-day Peruvian week, which is so often brought forward as a Semitic resemblance in the division of time in both continents, is founded upon a mere error, as has been already proved by Father Acosta, (*Hist. natural y moral de las Indias*, 1591, lib. vi. cap. 3,) who visited Peru soon after the Spanish conquest; and the Inca, Gar-

increased to seven; conjectures were prevalent, even in antiquity, that beyond these visible planets, there were yet other less luminous, unseen planets. This opinion is stated by Simplicius, to be Aristotelean. "It is probable that such dark cosmical bodies which revolve round the common centre, sometimes give rise to eclipses of the moon as well as the earth." Artemidorus of Ephesus, whom Strabo often mentions as a geographer, believed in the existence of an unlimited number of such dark revolving cosmical bodies. The old ideal body, the anti-earth (ἀντίχθων) of the Pythagoreans, does not belong to this class of conjectures. The earth and the anti-earth have a parallel concentric motion; and the anti-earth was conceived in order to avoid the assumption of the rotatory motion of the earth moving in a planetary manner round the central fire in twenty-four hours, can scarcely be anything else than the opposite hemisphere—the antipodean portion of our planet.[15]

When from the 43 principal and secondary planets now known (a number six times greater than that of the planetary bodies known to the ancients) the 36 objects which have been discovered since the invention of the telescope are chronologically separated according to the succession of their discovery, there is obtained for the seventeenth century, *nine;* for the eighteenth century, also *nine;* and for the half of the nineteenth century, *eighteen* newly discovered planets.

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cilaso de la Vega himself corrects his previous statement (parte i. lib. ii. c. 35,) by distinctly saying, there were three festivals in each of the months, which were reckoned after the moon, and that the people should work eight days and rest upon the ninth (parte i. lib. vi. cap. 23). The so-called Peruvian weeks, therefore, consisted of nine days. (See my *Vues des Cordillères*, tom. i. p. 341–343).

[15] Böckh, *über Philolaus*, p. 102 and 117.

Sequence of the planetary discoveries (of principal and secondary planets) since the invention of the telescope in the year 1608.

A. The Seventeenth Century.

Four satellites of Jupiter: Simon Marius, at Ansbach, December 29, 1609; Galileo, January 7, 1610, at Padua.

Triple configuration of SATURN: Galileo, November, 1610; Hevelius, hypothesis of two lateral bars, 1656; Huygens, final discovery of the true form of the ring, December 7, 1657.

The sixth satellite of Saturn (Titan): Huygens, March 25, 1655.

The eighth satellite of Saturn (the outermost, Japetus): Domin. Cassini, October, 1671.

The fifth satellite of Saturn (Rhea): Cassini, December 23, 1672.

The third and fourth satellites of Saturn (Tethys and Dione): Cassini, end of March, 1684.

B. The Eighteenth Century.

URANUS: William Herschel, May 13, 1781, at Bath.

The second and fourth satellites of Uranus: William Herschel, January 11, 1787.

The first satellite of Saturn (Mimas): William Herschel, August 28, 1789.

The second satellite of Saturn (Enceladus): William Herschel, September 17, 1789.

The first satellite of Uranus: William Herschel, January 18, 1790.

The fifth satellite of Uranus: William Herschel, February 9, 1790.

The sixth satellite of Uranus: William Herschel, February 28, 1794.

The third satellite of Uranus: William Herschel, March 26, 1794.

C. The Nineteenth Century.

CERES*: Piazzi, at Palermo, January 1, 1801.
PALLAS*: Olbers, at Bremen, March 28, 1802.
JUNO*: Harding, at Lilienthal, September 1, 1804.
VESTA*: Olbers, at Bremen, March 29, 1807.
(During 38 years no planetary discoveries were made).
ASTREA*: Hencke, at Driesen, December 8, 1845.
NEPTUNE: Galle, at Berlin, September 23, 1846.
The first satellite of Neptune: W. Lassell, at Starfield, near Liverpool, November, 1846; Bond, at Cambridge (U. S.).
HEBE*: Hencke, at Driesen, July 1, 1847.
IRIS*: Hind, in London, August 13, 1847.
FLORA*: Hind, in London, October 18, 1847.
METIS*: Graham, at Markree-Castle, April 25, 1848.
The seventh satellite of Saturn (Hyperion): Bond, at Cambridge (U. S.), September 16–19; Lassell, at Liverpool, September 19–20, 1848.
HYGEIA*: De Gasparis, at Naples, April 12, 1849.
PARTHENOPE*: De Gasparis, at Naples, May 11, 1850.
The second satellite of Neptune: Lassell, at Liverpool, August 14, 1850.
VICTORIA*: Hind, in London, September 13, 1850.
EGERIA*: De Gasparis, at Naples, November 2, 1850.
IRENE*: Hind, in London, May 19, 1851; and De Gasparis, at Naples, May 23, 1851.

In this chronological summary,[16] the principal planets are

[16] In the history of the discoveries, it is necessary to distinguish between the epoch at which the discovery was made,

distinguished from the secondary planets, or satellites, by larger type. Some bodies are included in the class of principal planets, which form a peculiar and very extended group, forming, as it were, a ring of 132 millions of geographical miles, situated between Mars and Jupiter, and are generally called small planets, as well as telescopic planets, co-planets, asteroids, or planetoids. Of these, 4 were discovered in the first seven years of this century, and 10 during the last six years; which latter circumstance is to be attributed less to the perfection of the telescopes, than the industry and dexterity of the investigators, and especially the improved charts, enlarged by additions of fixed stars of the ninth and tenth magnitudes. It is now more easy to distinguish between moving cosmical bodies and fixed. (See *Cosmos*, vol. iii. p. 155.)

The number of the principal planets has been exactly doubled since the first volume of Cosmos appeared,[17] so excessively rapid is the succession of discoveries, the extension and perfection of the topography of the planetary system.

2. *Classification of the planets in two groups.*—If the region

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and the time of its first announcement. In consequence of a neglect of this distinction, dissimilar and erroneous dates have been introduced into astronomical manuals. So, for example, Huygens discovered the sixth satellite of Saturn (Titan) on March 25, 1655 (*Huygenii Opera varia*, 1724, p. 523), and did not announce it until March 5, 1656 (*Systema Saturnium*, 1659. p. 2). Huygens, who devoted himself uninterruptedly from March, 1655, to the study of Saturn, had already obtained the full and indubitable view of the open ring on December 17, 1657, (*Systema Saturnium*, p. 21), but did not publish his scientific explanation of all the phenomena until the year 1659. (Galileo had thought that he saw, on each side of the planet, only two projecting circular discs.)

[17] *Cosmos*, vol. i. p. 76. Compare also Encke in *Schumacher's Astron. Nachr.*, vol. xxvi. 1848, No. 622, p. 347.

of small planets situated in the solar system between the orbits of Mars and Jupiter, but on the whole nearer to the former, is considered as a separating zone,—as it were an intermediate group;—then, as has already been remarked, those planets which are nearest to the sun, the interior (Mercury, Venus, the Earth, and Mars) present several resemblances among each other, and contrasts with the *exterior* planets (Jupiter, Saturn, Uranus, and Neptune), or those which are more remote from the sun, beyond this separating zone. Of these three groups, the intermediate one occupies a space scarcely equal to half the distance of the orbit of Mars from that of Jupiter. Of the space between the two great principal planets, Mars and Jupiter, that part which is nearest to Mars is, as far as has hitherto been observed, the most closely filled; for if, in the zone which the asteroids occupy, the two outermost, Flora and Hygeia, are examined, it will be found that Jupiter is more than three times further from Hygeia than Flora is from Mars. The most distinctive features of this intermediate group of planets, are the great inclination and eccentricity of their interlacing orbits; and the extreme smallness of the planets. The inclination of the orbits towards the ecliptic increases in that of Juno to 13° 3′, in that of Hebe even to 14° 47′, of Egeria to 16° 33′, of Pallas even to 34° 37′: while in the same intermediate group, it falls as low, in the orbit of Astrea, as 5° 19′, in that of Parthenope to 4° 37′, and that of Hygeia to 3° 47′. The whole of the orbits of the small planets having inclinations smaller than 7°, are, to go from the large to the small, those of Flora, Metis, Iris, Astrea, Parthenope, and Hygeia. Nevertheless, none of these orbits attain such a small degree of inclination as those of Venus, Saturn, Mars, Neptune, Jupiter, and Uranus. The eccentricities partly exceed even that of Mercury (0·206); for Juno, Pallas, Iris, and Victoria have 0·255, 0·239, 0·232, and 0·218; while Ceres (0·076)

Egeria (0·086), and Vesta, (0·089) have orbits less eccentric than Mars (0·093), without, however, attaining to the approximative circular orbits of the other planets (Jupiter, Saturn, and Uranus). The diameter of the telescopic planets is immensurably small; and according to observations made by Lamont in Munich, and Mädler with the Dorpat refractor, it is probable that the largest of the small planets is at the utmost only 580 geographical miles in diameter; that is, $\frac{1}{5}$ of that of Mercury, $\frac{1}{12}$ that of the earth.

If the 4 planets nearest to the sun, situated between the ring of the asteroids (the small planets) and the central body, are called *interior planets*, they will all agree in presenting a moderate size, a greater density less flattened at the poles, and at the same time rotating slowly round their axes (in periods of rotation of nearly 24 hours), and with the exception of one (the earth) without moons. On the contrary, the 4 exterior planets, those which are more remote from the sun, situated between the ring of asteroids, and the, to us, unknown limits of the solar system (Jupiter, Saturn, Uranus, and Neptune) are considerably larger, five times less dense, their axial rotation more than twice as rapid, and their number of moons greater in the proportion of 20 to 1. The *interior* planets are all smaller than the earth (Mercury and Mars $\frac{2}{5}$ and $\frac{1}{2}$ smaller in diameter); the exterior planets, on the contrary, are from 4·2 to 11·2 larger than the Earth. The density of the Earth being taken as = 1, the densities of Venus and Mars are the same to within less than $\frac{1}{10}$; the density of Mercury is also but very little more, according to Encke's determination of his mass. On the contrary, none of the exterior planets exceed in density $\frac{1}{4}$; Saturn, indeed, is only $\frac{1}{7}$, almost only half the density of the other exterior planets and the sun. The exterior planets present the solitary phenomenon of the whole solar system, the wonderful circumstance of one of its principal planets being surrounded by an unattached ring;

also atmospheres which, in consequence of the peculiarity of their condensation, appear to us variable; in Saturn, indeed, sometimes as interrupted bands.

Although in the important classification of the planets into two groups of *interior* and *exterior* planets, the general characters of absolute magnitude, density, flattening at the poles, velocity of rotation, absence of moons, present themselves as dependent upon the distances, *i. e.*, from their semi orbital axes, this dependence cannot be affirmed of each one of these groups. Up to the present time we are ignorant, as I have already remarked, of any internal necessity, any mechanical law of nature, which (like the beautiful law which connects the square of the periods of revolution with the cube of the major axes) represents the above-named elements of the order of succession of the individual planetary bodies of each group, in their dependence upon the distances. Although the planet which is nearest to the sun (Mercury) is the densest, even six or eight times denser than some of the exterior planets, Jupiter, Saturn, Uranus, and Neptune, the order of succession, in the case of Venus, the Earth, and Mars, or Jupiter, Saturn, and Uranus, is very irregular. The absolute magnitudes do generally, as Kepler has already observed (*Harmonice Mundi*, vol. iv. p. 194; *Cosmos*, vol. i. pp. 77–82), increase with the distances; but this does not hold good when the planets are considered individually. Mars is smaller than the Earth, Uranus smaller than Saturn, Saturn smaller than Jupiter, and succeeds immediately to a host of planets, which, on account of their smallness, are almost immeasurable. It is true the period of rotation generally increases with the distance from the sun; but it is, in the case of Mars, slower than in that of the Earth, slower in Saturn than in Jupiter.

The external world of forms, I again repeat it, can only be represented in the enumeration of relations of space, as some-

thing actually existing in nature; and not as the subject of intellectual deductions of previously known causal relations. No universal law for the cosmical regions is here traced, any more than for terrestrial regions in the culminating points of mountain-chains, or in the configuration of continents. These are natural facts which have resulted from the conflict of numerous attractive and repulsive forces, under conditions which are unknown to us. We here enter with eager and unsatisfied curiosity upon the obscure domain of *incipient formation.* It is to these phenomena that the so-frequently misused term of *natural facts* may be applied in its strictest sense, cosmical processes which have taken place during spaces of time of, to us, immeasurable extent. If the planets have been formed from revolving rings of nebulous matter, it must, after having commenced to aggregate into globes, according to the preponderating influence of individual centres of attraction, have passed through an interminable series of conditions in order to have formed sometimes simple, sometimes interwoven orbits, planets of such different magnitudes, flattening, and density, with and without moons, and even in one case to blend the satellites into a solid ring. The present form of things, and the exact numerical determinations of their relations, has not hitherto been able to lead us to a knowledge of the past states, or a clear insight into the conditions under which they originated. These conditions must not, however, on that account be called *accidental*, as men call everything whose genetic organ they are not able to explain.

3. *Absolute and apparent magnitude; Configuration.*—The diameter of the largest of all the planets (Jupiter) is 30 times as great as the diameter of the smallest of those which have been determined with certainty (Mercury); nearly 11 times as great as the diameter of the Earth. Very nearly the same relation obtains between Jupiter and the Sun. Their diameters are nearly as 1 to 10. It has been asserted, perhaps

erroneously, that the difference in size of the meteoric stones which there is a tendency to consider as small planetary bodies, from Vesta, which, according to a measurement by Mädler, is 264 geographical miles in diameter, therefore 380 miles less than the diameter of Pallas according to Lamont, not greater than the difference between Vesta and the Sun. According to these relations, there must be meteoric stones of 517 feet in diameter. Fire-balls certainly have, while they retain a disc-like appearance, a diameter amounting to 2,600 feet.

The dependence of the flattening at the poles upon the velocity of rotation, appears most strikingly in the comparison of the Earth as a planet of the interior group (Rot. 23^h $56'$., Flattening $\frac{1}{299}$) with the exterior planet Jupiter (Rot. 9^h $55'$, Flattening, according to Arago, $\frac{1}{17}$, according to John Herschel $\frac{1}{13}$), and Saturn (Rot. 10^h $29'$, Flattening $\frac{1}{10}$.) But Mars, whose rotation is still 41 minutes slower than the rotation of the Earth, has, even when a much smaller result is assumed than that of William Herschel, very probably a much greater flattening. Does the reason of this anomaly, inasmuch as the figure of the surface of an elliptical spheroid ought to correspond with the velocity of rotation, consist in the difference of the law of the increasing density towards the centre of the superincumbent strata? or in the circumstance that the liquid surface of some planets was solidified before they could assume the figure appertaining to their velocity of rotation? The important phenomena of the backward motion of the equinoctial points or the apparent advance of the stars (precession), that of *nutation* (oscillation of the earth's axis), and the variation of the inclination of the ecliptic, depend, as theoretical astronomy proves, upon the configuration.

The absolute magnitudes of the planets, and their distance from the earth, determine their apparent diameter. We

have, therefore, to arrange the planets according to their absolute (actual) magnitudes, proceeding from the larger to the smaller:

The small planets with involved orbits, of which the largest appears to be Pallas and Vesta:—

Mercury,	Neptune,
Mars,	Uranus,
Venus,	Saturn,
Earth,	Jupiter.

The apparent equatorial diameter of Jupiter, at a mean distance from the earth, is 38″·4, while that of Venus, which is nearly equal in magnitude to the Earth, is only 16″·9; that of Mars 5″·8. But the apparent diameter of the disc of Venus increases in the inferior conjunction to 62″, while that of Jupiter attains only an increase to 46″. It is necessary to call to mind in this place that the point of the orbit of Venus at which it appears to us with the brightest light, falls between the inferior conjunction and her greatest digression from the sun, because in that position the small luminous crescent gives the most intense light, on account of its greatest proximity to the Earth. Upon the average, Venus appears the most beautifully luminous, even casting shadows in the absence of the sun, when at a distance of 40° east or west from the sun; the apparent diameter then amounts to only 40″, and the greatest width of the illuminated phase is scarcely 10″.

Apparent Diameter of Seven Planets.

Mercury	at a mean	distance	6″·7	(oscillates from	4″·4 to 12″)
Venus	,,	,,	16″·9	(,,	9″·5 to 62″)
Mars	,,	,,	5″·8	(,,	3″·3 to 23″)
Jupiter	,,	,,	38″·4	(,,	30″ to 46″)
Saturn	,,	,,	17″·1	(,,	15″ to 20″)
Uranus	,,	,,	3″·9		
Neptune	,,	,,	2″·7		

The volumes of the planets in relation to the earth are—

Mercury	as	1	:	16·7
Venus	„	1	:	1·05
Earth	„	1	:	1
Mars	„	1	:	7·14
Jupiter	„	1414	:	1
Saturn	„	735	:	1
Uranus	„	82	:	1
Neptune	„	108	:	1

while the volume of the Sun is to that of the Earth = 1407124 : 1. Small alterations in the measurements of the diameters increase the data of volumes in the ratio of their cubes.

The moving planets which agreeably enliven the aspect of the heavens, influence us simultaneously by the magnitudes of their discs and their proximity, by the colour of their light, by scintillation,—which is not entirely wanting to some planets, in certain positions—and by the peculiarity with which their different surfaces reflect the Sun's light. Whether a feeble evolution of light from the planets themselves modifies the intensity and properties of their light, is a problem which still remains to be solved.

4. *Arrangement of the Planets and their Distances from the Sun.*—In order to form a general conception of the planetary system as a whole, so far as it is yet known, and to represent it in its mean distances from the central body, the Sun, the following table is given, in which, as has always been the custom in astronomy, the mean distance of the Earth from the Sun (82728000 geographical miles) is taken as unity. The greatest and smallest distances of the individual planets from the Sun in aphelion and perihelion,—according as the planet is situated in the ellipse whose focus is occupied by the Sun, at that point of the major axis (line of apsides) which is the farthest from or nearest to the focus,—will be

added afterwards when treating of the planets individually. By the mean distance from the Sun, of which alone mention will be made in this place, is to be understood the mean of the greatest and smallest distance, or the *half major axis* of the planet's orbit. It must also be observed, that the numerical data employed, both previously and hereafter, are for the most part taken from Hausen's careful classification of the planetary elements in Schumacher's *Jahrbuch* for 1837. Where the data refer to time, they are, in the case of the older and larger planets, for the year 1800; but in the case of Neptune, for the year 1851, by the aid of the Berlin *Astronomische Jahrbuch* of 1853. The comparison of the small planets occurring afterwards, and for which I am indebted to Dr. Galle, refers exclusively to more recent epochs.

Distances of the Planets from the Sun.

Mercury	0·38709
Venus	0·72333
Earth	1·00000
Mars	1·52369

Small Planets.

Flora	2·202
Victoria ...	2·335
Vesta	2·362
Iris	2·385
Metis	2·386
Hebe	2·425
Parthenope ...	2·448
Irene	2·553
Astrea	2·577
Egeria	2·579
Juno	2·669
Ceres	2·768
Pallas	1·773
Hygeia	3·151

Jupiter	5·20277
Saturn	9·53885
Uranus	19·18239
Neptune...	30·03628

The simple observation of rapidly diminishing periods of revolution, from those of Saturn and Jupiter to Mars and Venus, led, at a very early time, under the assumption that the planets were attached to movable spheres, to conjectures as to the distances of these spheres from each other. As there are no traces of methodically-instituted observations and measurements to be found among the Greeks before the time of Aristarchus of Samos, and the establishment of the Alexandrinian Museum, a great difference arose in the hypotheses as to the arrangement of the planets and their relative distances: whether according to the most prevailing system, with reference to their distances from the Earth as the fixed centre: or, as among the Pythagoreans, with reference to the distances from the focus of the universe. The principal subject on which there was a discrepancy of opinion was the position of the Sun, that is, its relative situation in reference to the inferior planets and the Moon.[18] The Pythagoreans, who considered *number* to be the source of all knowledge, the real essence of all existing things, applied their theory of numbers, the all-blending doctrine of numerical relations, to the geometrical consideration of the five regular bodies, to the musical intervals of tone which determine accord, and form different kinds of sounds, and even to the system

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[18] Böckh, *de Platonico Syst.* p. xxiv. and in *Philolaos*, p. 100. The succession of the planets which, as we have just seen (Note 14), gave rise to the naming of the week-days after the planetary deities, that of Geminus, is distinctly called the oldest by Ptolemæus. (*Almag.* xi. cap. i.) He blames the motives from which "the moderns have placed Venus and Mercury beyond the Sun."

of the universe itself, supposing that the moving, and, as it were, vibrating planets, exciting sound-waves, must produce a spheral music, according to the harmonic relations of their intervals of space. "This music," they add, "would be perceived by the human ear if it was not rendered insensible by extreme familiarity, as it is perpetual, and men are accustomed to it from childhood."[19] The harmonic part of the Pythagorean doctrine of numbers thus became connected with the figurative representation of the Cosmos precisely in the Platonic Timæus; for "cosmogony is to Plato the work of the union of opposite first causes, brought about by harmony."[20] He attempted, moreover, to illustrate the tones of the universe in an agreeable picture, by attributing to each of the planetary spheres a syren, who, supported by the stern daughters of Necessity, the three Fates, maintain the eternal revolution of the world's axis."[21] Such a representation of the Syrens, in whose place the Muses are sometimes substituted, as the choir of heaven, has been, in many cases,

[19] The Pythagoreans affirm, in order to justify the reality of the tones produced by the revolution of the spheres, that hearing takes place only where there is an alternation of sound and silence. Aristot. *de Cælo*, ii. 9, p. 290, No. 24–30, Bekker. The inaudibility of the spheral music is also accounted for by its overpowering the senses. Cicero, *de Rep.* vi. 18. Aristotle himself calls the Pythagorean tone-myth pleasing and ingenious, (κομψῶς καὶ περιττῶς,) but *untrue*, (l. c. no. 12–15.)

[20] Böckh in *Philolaus*, p. 90.

[21] Plato, *de Republica*, x, p. 617. (*Davis' Translation. Bohn's Class. Lib.* p. 307.) He estimates the planetary distances according to two entirely different progressions, one by doubling, the other by tripling, from which results the series, 1. 2. 3. 4. 8. 9. 27. It is the same series which is found in the Timæus, where the subject of the arithmetical division of the world--spirit, (p. 35, Steph.. *Davis' Trans. Bohn's Class. Lib.*) which Demiurgus propounds, is treated of. Plato had, indeed, considered

handed down to us in antique monuments, especially in carved stones. Mention is constantly made of the harmony of the spheres, although generally reproachfully, throughout the writings of Christian antiquity, and all those of the middle ages, from Basil the Great to Thomas Aquinas and Petrus Alliacus.[22]

At the close of the sixteenth century, all the Pythagorean and Platonic views of the system of the universe were again reanimated in the person of the imaginative Kepler. He, in the first instance, constructed the planetary system in the *Mysterium Cosmographicum*, in accordance with the principle of the five regular solids, which may be imagined as situated between the planetary spheres, then in the *Harmonice Mundi*, according to the intervals of tone.[23] Convinced of the regularity of the relative distances of the planets, he

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the two geometrical progressions, 1. 2. 4. 8 and 1. 3. 9. 27 together, and thus alternately taken each successive number from one of the two series, whence resulted the above-mentioned succession 1. 2. 3. 4. 9......Compare Böckh in the *Studien von Daub und Creuzer*, bd. iii. pp. 34–43; Martin, *Etudes sur le Timée*, tom. i. p. 384, and tom. ii. p. 64. (Compare also Prevost, *Sur l'Ame d'après Platon*, in the *Mém. de l'Acad. de Berlin* for 1802, pp. 90 and 97; the same in the *Bibliothèque Britannique, Sciences et Arts*, tom. xxxvii. 1108, p. 153.

[22] See the acute work of Professor Ferdinand Piper, *Von der Harmonie der Sphären*, 1850, pp. 12–18. The supposed relation of the seven vowels of the old Egyptian language to the seven planets, and Gustav Seyffarth's conception, already disproved by Zoega's and Tölken's investigations, of the astrological hymns, rich in vowels, of the Egyptian priests, according to passages of Pseudo-Demetrius Phalæreus (perhaps Demetrius of Alexandria,) an epigram of Eusebius, and a Gnostic manuscript in Leyden, have been minutely treated of with critical erudition by the younger Ideler, (*Hermapion*, 1841, pars i. pp. 198–214). Compare also Lobeck, *Aglaoph*. tom. ii. p. 932.

[23] On the gradual development of the musical ideas of

believed that he had solved the problem by a happy combination of his earlier and later views. It is extremely remarkable that Tycho Brahe, who in other respects is found to be so strictly attached to actual observation, had already expressed the opinion (controverted by Rothman), that the revolving cosmical bodies were capable of vibrating the celestial air (what we now call resisting medium,) so as to produce tones.[24] But the analogies between the relations of tone and the distances of the planets, which Kepler so long and laboriously endeavoured to trace out, remained, in his opinion, as it appears to me, entirely with the domain of abstract speculation. He congratulated himself upon having, to the greater glorification of the Creator, discovered musical relations of number in the relations of cosmical space; as if in poetic enthusiasm, he makes "Venus, together with the Earth, sound sharp in aphelion and flat in perihelion; the highest tone of Jupiter and that of Venus must coincide in flat accord." In spite of these merely symbolical expressions, so frequently employed, Kepler says positively:—"Jam soni in cœlo nulli existunt, nec tam turbulentus est motus, ut ex attritu *auræ cœlestis* eliciatur stridor.[*] (*Harmonice Mundi*, lib. v. cap. 4.) The thin and clear celestial air (aura cœlestis) is also mentioned here again.

The comparative consideration of the planetary intervals with the regular bodies which would fill these intervals, encouraged Kepler to extend his hypothesis even so far as the region of fixed stars.[25] The circumstance which on the occa-

Kepler, vide Apelt's Commentary of the *Harmonice Mundi*, in his work; Johann Keppler's *Weltansicht*, 1849, p. 76–116. (Compare also Delambre, *Hist. de l'Astronom. mod.* tom. i. pp. 352–360.)

[24] Cosmos, vol. ii. p. 697.

[*] Now there are no such things as sounds among the heavenly bodies, nor is their motion so turbulent, as to elicit noise from the attrition of the celestial air.

[25] Tycho had denied the existence of the crystalline

sion of the discovery of Ceres, and the other so-called *small planets*, first forcibly recalled to mind Kepler's Pythagorean arguments, was his almost forgotten conjecture as to the probable *existence of a yet unseen planet in the great planetless chasm between Mars and Jupiter.* ("Motus semper distantiam pone sequi videtur; atque ubi magnus hiatus erat inter orbes, erat et inter motus."*) "I have become more daring," he says, in the introduction to the *Mysterium Cosmographicum*, "and place a new planet between Jupiter and Mars, as also (a conjecture which was less fortunate, and remained long unnoticed,[36]) another planet between Venus and Mercury; neither

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spheres, in which the planets were supposed to be fixed. Kepler praised the undertaking, but he still adhered to the opinion that the sphere of fixed stars was a solid globular shell of two German miles in thickness, upon which are the twelve fixed stars, which are all situated at equal distances from us, and have a peculiar relation to the corners of an icosahedron. The fixed stars "lumina sua ab *intus* emittunt;" "emit light from their own bodies:" he also considered for a long time that the planets were self-luminous, until Galileo taught him better! Although he, like many other of the ancients and Giordano Bruno, considered the fixed stars to be suns like our own, still he was not much inclined to entertain the opinion, which he had well considered, that all fixed stars are surrounded by planets, as I had formerly stated him to be. (*Cosmos*, vol. ii. p. 711.) Compare Apelt. *Commentary to the Harmonice*, pp. 21–24.

* "There seems to be always a close relation between the motion and the distance [of the planets]: that is to say, where there is a great interval between their orbs, the same exists also between their motions."

[36] It was not until the year 1821 that Delambre, in the *Hist. de l'Astron. Mod.* tom. i. p. 314, directed attention to the planets which Kepler conjectured to lie between Mercury and Venus, in the extracts which are complete with regard to astronomy, but not with regard to astrology, from Kepler's collected works (pp. 314–615). "On n'a fait aucune attention à cette supposition de Kepler, quand on a formé des projets

of these have been seen, probably on account of their extreme smallness.[27] Kepler subsequently found that he did not require these new planets for his solar system founded upon

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de découvrir la planète qui (selon une autre de ces prédictions) devait circuler entre Mars et Jupiter." "No attention was paid to that supposition of Kepler's, when projects were formed for discovering the planet which (according to another of his predictions) ought to revolve between Mars and Jupiter."

[27] The remarkable passage respecting a space to be filled up between Mars and Jupiter [hiatus] is in Kepler's *Prodromus Dissertationum cosmographicarum, continens Mysterium cosmographicum de admirabili proportione orbium cœlestium*, 1596, p. 7:—"Cum igitur hac non succederet, alia via, mirum quam audaci, tentavi aditum. Inter Jovem et Martem interposui novum planetam, itemque alium inter Venerem et Mercurium, quos duos forte ob exilitatem non videamus, iisque sua tempora periodica ascripsi. Sic enim existimabam me aliquam æqualitatem proportionum effecturum, quæ proportiones inter binos versus Solem ordine minuerentur, versus fixas augescerent: ut propior est Terra Veneri quantitate orbis terrestris, quam Mars Terræ, in quantitate orbis Martis. Verum hoc pacto neque unius planetæ interpositio sufficiebat ingenti hiatu, Jovem inter et Martem: manebat enim major Jovis ad illum novum proportio, quam est Saturni ad Jovem. Rursus alio modo exploravi." "When this plan therefore failed, I tried to reach my aim in another way, of, I must confess, singular boldness. Between Jupiter and Mars I interposed a new planet, and another also between Venus and Mercury, both which it is possible are not visible on account of their minuteness, and I assigned to them their respective periods. For in this way I thought that I might in some degree equalize their ratios, which ratios regularly diminished towards the Sun, enlarged towards the fixed stars: as the Earth is nearer to Venus than Mars is to the Earth. But even in this way the interposition of one planet did not supply the great chasm between Jupiter and Mars, for the ratio between Jupiter and the supposed new planet still remained greater than between Saturn and Jupiter. Again I tried in another way." Kepler was twenty-five years of age when he wrote this. It may be seen how his restless mind formed hypotheses, and again

the properties of the regular solids; it was only necessary to modify the distances of the old planets a little arbitrarily. ("Non reperies novos et incognitos planetas, ut paulo antea, interpositos, non ea mihi probatur audacia; sed illos veteres *parum admodum luxatos.*"*—*Myst. Cosmogr.* p. 10.) The ideal tendencies of Kepler were so analogous to those of the Pythagorean school, and still more to those of Plato expressed in the *Timæus*,† that in the same way as Plato (*Cratyl.* p. 409) assumed, in addition to the differences of tone in the planetary spheres, those of colour, Kepler likewise instituted some experiments (*Astron. Opt.* cap. 6, p. 261) for the purpose of detecting the colours of the planets. Even the great Newton, always so precise in his conclusions, was inclined, as Prevost has already remarked (*Mém. de l'Acad. de Berlin*, for 1802, pp. 77 and 93) to reduce the dimensions of the seven colours of the spectrum to the diatonic scale.[28]

quickly forsook them, to deceive himself with others. He always retained a hopeful faith in being able to discover numerical laws where matter had aggregated under the manifold disturbances of attractive forces, (disturbances whose combinations are incalculable, as are so many past events and formations on account of our ignorance of the accompanying conditions) aggregated into globes, revolving in orbits, sometimes simple and almost parallel, sometimes grouped together and surprisingly complicated.

* "You will not find new and unknown planets, as I said before; that boldness I do not approve of; but you will find the old ones a little altered in position."

† *Plato's Works translated*, vol. ii. Bohn's Classical Library.

[28] Newtoni *Opuscula Mathematica, Philosophica et Philologica*, 1744, tom. ii. Opusc. xviii. p. 246:—"Chordam musice divisam potius adhibui, non tantum quod cum phænominis (lucis) optime convenit, sed quod fortasse, aliquid circa colorum harmonias (quarum pictores non penitus ignari sunt), sonorum concordantiis fortasse analogas, involvat. Quemadmodum verisimilius videbitur animadvertenti affinitatem, quæ est inter extimam Purpuram (Violarum colorem)

The hypothesis of yet unknown members of the planetary series, calls to mind the opinion of Hellenic antiquity, that there were far more than five planets; these were, indeed, all that had been observed, but many others might remain unseen, on account of the feebleness of their light and their position. Such a doctrine was especially attributed to Artemidorus of Ephesus.[29] Another old Hellenic, and perhaps even Egyptian belief appears to have been, that "the celestial bodies which we now see, were not all visible in earlier times." Connected with such a physical or much rather historical myth, is the remarkable form of the praise of a high antiquity which some races ascribed to themselves.

Thus the pre-Hellenic Pelasgian inhabitants of Arcadia called themselves *Proselenes;* because they boasted that they came into the country before the Moon accompanied the Earth. Pre-Hellenic and pre-lunarian were synonymous. The appearance of a star was represented as a celestial event, as the Deucalionic flood was a terrestrial event. Apuleius (*Apologia*, vol. ii. p. 494, ed. Oudendorp; *Cosmos*, vol. ii.

ac Rubedinem, colorum extremitates, qualis inter octavæ terminos (qui pro unisonis quodammodo haberi possunt) reperitur." "I preferred employing the divisions of the musical chord, not only because they harmonize best with the phenomena [of light], but because it is possible there may be some latent analogy between the harmonies of colours (with which painters are not altogether unacquainted) and the concords of sounds. This will appear more probable to any one who shall notice the similarity of relations between violet and red, the extreme colours [on the spectrum], and the highest and lowest notes of the octave, which somehow may be considered as in unison." Compare also Prevost, in the *Mém. de l'Acad. de Berlin*, for 1802, pp. 77 and 93.

[29] Seneca, *Nat. Quæst. VII.* 13:—"Non has tantum stellas quinque discurrere, sed solas observatas esse: ceterum innumerabiles ferri per occultum." "Not that these five stars only moved, but that they only had been observed, for a countless number are borne along beyond the reach of vision."

p. 557, note,) extends the flood as far as the Getulean mountains of Northern Africa. Apollonius Rhodius, who according to Alexandrian custom, was fond of imitating old models, speaks of the early colonization of the Egyptians in the valley of the Nile: "the stars did not yet revolve in the heavens; nor had the Danaides yet appeared, or the race of Deucalion."[30]. This important passage explains the praise of the Pelasgian Arcadia.

[30] Since the explanations which Heyne has given of the origin of the astronomical myth of the Proselenes, so widely diffused in antiquity (*De Arcadibus Luna Antiquioribus*, in *Opusc. Acad.* vol. ii. p. 332,) were unsatisfactory to me, I was greatly rejoiced to receive from my acute philological friend, Professor Johannes Franz, a new and very happy solution of this much-debated problem, by simple combinations of ideas. This solution is unconnected with either the arrangement of the calendar by the Arcadians, or their worship of the Moon. I restrict myself here to an extract from an unpublished and more extended work. This explanation will not be unwelcome to some of my readers in a work in which I have made a rule frequently to trace back the whole of our present knowledge to the knowledge of the ancients, and even to traditions believed generally or by very many.

"We shall commence with a few of the principal passages from the ancients, which treat of the Proselenes. Stephanus of Byzantium (v. Ἀρκάς) mentions the logographs of Hippys, of Rhegium, a contemporary of Darius and Xerxes, as the first who called the Arcadians προσελήνους. The scholiasts, *ad Apollon. Rhod. IV.* 264, and *ad Aristoph. Nub.* 397, agree in saying, the remote antiquity of the Arcadians becomes most clear from the fact of their being called προσέληνοι. They appear to have been there before the Moon, as Eudoxus and Theodorus also say; the latter adds that it was shortly before the labours of Hercules that the Moon appeared. In the government of the Tegeates, Aristotle states that the barbarians who inhabited Arcadia were driven out by the later Arcadians before the Moon appeared, and therefore they were called προσέληνοι. Others say, Endymion discovered the revolution of the Moon, but as he was an Arcadian, his

I conclude these considerations respecting the distances of the planets, and their arrangement in space, with a law, which however scarcely deserves this name, and which is

countrymen were called after him προσέληνοι. Lucian expresses himself slightingly. (*Astrolog.* 26.) According to him it was from stupidity and folly that the Arcadians said they were there before the Moon. In the *Schol. ad Æschyl. Prom.* 436, it is observed, that προσελούμενον is called ὑβριζόμενον, whence, therefore, the Arcadians were called προσέληνοι, because they are arrogant. The passages in Ovid as to the existence of the Arcadians before the Moon, are universally known. Recently, indeed, the idea has sprung up that all the ancients were deceived by the form προσέληνοι, and that the word (properly προέλληνοι) meant only pre-Hellenic, as Arcadia certainly was a Pelasgian country.

"If, now, it can be proved," continues Professor Franz, "that another people connected their origin with another cosmical body, the trouble of taking refuge in deceptive etymological explanations will be obviated. This kind of testimony exists in the most suitable form. The learned rhetorician Menander says literally in his work, *De Encomiis* (sec. ii. cap. 3, ed. Heeren), as follows:—'A third motive for the praise of objects is the time; this is the case in all the most ancient nations: when we say of a town or of a country it was founded before this or that star, or with those stars, before the flood or after the flood; as the Athenians affirm they originated at the same time as the Sun, the Arcadians before the Moon, the Delphians immediately after the flood; these are epochs, and, as it were, starting-points in time.'

"Therefore Delphi, the connection of which with the flood of Deucalion is otherwise proved (*Pausan.* x. 6), is surpassed by Arcadia, and Arcadia by Athens. Apollonius Rhodius, who was so fond of imitating old models, expresses himself quite in accordance with this passage, where he says (iv. 261), Egypt is said to have been inhabited before all other countries; 'the stars did not yet all revolve in the heavens; the Danaides had not yet appeared, nor the race of Deucalion; the Arcadians alone existed; those of whom it is said, that they lived before the Moon, eating acorns upon the mountains.' In the same manner, *Nonnus* (xli.) says of the Syrian Beroë, that it was inhabited before the time of the Sun.

called by Lalande and Delambre, a play of numbers; by others, a help for the memory. It has greatly occupied our laborious Bode, especially at the time that Piazzi discovered Ceres: a circumstance, however, which was in no way occasioned by that so called law, but rather by a misprint in Wollaston's *Catalogue of the Stars*. If any one is inclined to consider that discovery as the fulfilment of a prediction, it must not be forgotten that the latter, as we have already pointed out, extends back as far as Kepler, or more than a century and a half beyond Titius and Bode. Although the

"Such a habit of deriving determinations of time from epochs in the formation of the world, is an offspring of the speculative period, in which all objects have still more vitality, and is most closely allied to the genealogical local poetry. So that it is not improbable that the tradition sung by an Arcadian poet of the battle of the giants in Arcadia, to which the above-quoted words of old Theodorus (whom some consider to be a Samothracian, and whose work must have been very comprehensive) refer, may have given occasion to the general application of the epithet προσέληνοι to the Arcadians." With regard to the double names 'Arkades Pelasgoi,' and the opposition of a more ancient or recent peopling of Arcadia, compare the excellent work, *Der Peloponnesos*, by Ernst Curtius, 1851, pp. 160 and 180. In the New Continent also there is, as I have already shown in another place (see my *Kleinen Schriften*, Bd. i. p. 115), upon the elevated plain of Bogotá, the race of Muyscas, or Mozcas, who in their historical myths boast of a proselenic antiquity. The origin of the Moon is connected with the tradition of a great flood, which a woman who accompanied the miracle-worker Botschika had caused by her magical arts. Botschika drove away the woman (called Huythaca or Schia). She left the Earth, and became the Moon, "which until then had never shone upon the Muyscas." Botschika, pitying the human race, opened a steep rocky wall near Canoas, where the Rio de Tunzha now rushes down, forming the famous waterfall of Tequendama. The valley, filled with water, was then laid dry,—a geognostic romance which occurs repeatedly: for example, in the closed Alpine valley of Cashmir, where the mighty drainer is called Kasyapa.

Berlin astronomer had already distinctly declared, in the second edition of his popular and extremely useful *Anleitung zur Kenntniss des gestirnten Himmels*, that "he had taken the law of the distances from a translation of Bonnet's *Contemplation de la Nature*, prepared by Professor Titius at Wittenberg," still it has generally borne his name, and seldom that of Professor Titius. In a note which the latter added to the chapter on the System of the Universe,[21] he says: "When the distances of the planets are examined, it is found that they are almost all removed from each other by distances which are in the same proportion as their magnitudes increase. If the distance from Saturn to the Sun is taken as 100 parts, the distance of Mercury from the Sun is 4 such parts, that of Venus $4 + 3 = 7$ such parts, the Earth $4 + 6 = 10$, Mars $4 + 12 = 16$. But from Mars to Jupiter there is a deviation from this accurate (!) progression. Mars is followed by a space of $4 + 24 = 28$ such parts, in which neither a principal planet nor a subordinate planet has yet been seen. Is it possible that the Creator should have left this space empty? It cannot be doubted that this space belongs to yet undiscovered satellites of Mars; or that perhaps even Jupiter has further satellites around him, which have not hitherto been seen by any telescope. In this space (unknown to us as regards its contents) Jupiter's circle of action extends to $4 + 48 = 52$. Then follows Saturn in $4 + 96 = 100$ parts—an admirable proportion." Titius was therefore inclined to consider the space between Mars and Jupiter as containing, not one, but, as is actually the case, several cosmical bodies; however, he conjectured that they were more likely to be subordinate, than principal planets.

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[21] Karl Bonnet, *Betrachtung über die Natur*, translated by Titius, second edition, 1772, p. vii. note 2 (the first edition appeared in 1766). In Bonnet's original work no such law is noticed. (Compare also Bode, *Anleit. zur Kenntniss des gestirnten Himmels*, second edition, 1772, p. 462.)

How the translator and commentator of Bonnet obtained the number 4 for the orbit of Mercury, is nowhere stated. Perhaps he selected it only in order to have in combination with the easily divisible numbers 96, 48, 24, &c., exactly 100 for Saturn, at that time the most distant planet known, whose distance is 9·5, thus very nearly = 10·0. It is less probable that he constructed the order of succession by commencing from the nearer planets. A sufficient correspondence of the law of duplication setting out, not from the Sun, but from Mercury, with the true planetary distances, could not have been affirmed in the last century, as the latter were known at that time with sufficient accuracy for this purpose. In reality, the distances between Jupiter, Saturn, and Uranus approximate very closely to the duplication; nevertheless, since the discovery of Neptune, which is much too near to Uranus, the defectiveness in the progression has become strikingly evident.[32]

[32] Since, according to Titius, the distance from the Sun to Saturn, then the outermost planet, is taken as = 100, the individual distances should be:

Mercury,	Venus,	Earth,	Mars,	Small planets,	Jupiter,
$\frac{4}{100}$	$\frac{7}{100}$	$\frac{10}{100}$	$\frac{16}{100}$	$\frac{28}{100}$	$\frac{52}{100}$

according to the so-called progression: 4, 4+3, 4+6, 4+12, 4+24, 4+48; consequently, when the distance of Saturn from the Sun is taken as 789·2 million geographical miles, those of the other planets expressed in the same measure, are:

Distances, according to Titius, in geographical miles.		Actual distance in geographical miles.
Mercury	31·6 millions.	32·0 millions.
Venus	55·2 „	60·0 „
Earth	78·8 „	82·8 „
Mars	126·0 „	126·0 „
Small planets ...	220·8 „	220·8 „
Jupiter	410·4 „	430·0 „
Saturn	789·2 „	789·2 „
Uranus	1586·8 „	1586·8 „
Neptune	3062·0 „	2484·8 „

What is called the law of Wurm of Leonberg, and sometimes distinguished from the law of Titius and Bode, is merely a correction which Wurm made as to the distance of Mercury from the Sun, and the difference between the distances of Mercury and Venus. Approximating nearer to the fact, he fixes the former as 387, the latter 680, and the distance of the Earth 1,000.[33] Gauss had already, on the occa-

[33] Wurm, in *Bode's Astron. Jahrbuch* for the year 1790, p. 168; and Bode, *Von dem neuen zwischen Mars und Jupiter entdeckten achten Hauptplaneten des Sonnensystems*, 1802, p. 45. With the numerical correction of Wurm, the series, according to the distances from the Sun, is:—

			Parts.
Mercury	387		
Venus	387 +	293 =	680
Earth	387 +	2·293 =	973
Mars	387 +	4·293 =	1559
Small planets	387 +	8·293 =	2731
Jupiter	387 +	16·293 =	5075
Saturn	387 +	32·293 =	9763
Uranus	387 +	64·293 =	19139
Neptune	387 +	128·293 =	37891

In order that the degree of accuracy of these results may be tested, the actual mean distances of the planets are given in the next table as they are acknowledged at the present time, with the addition of the numbers which Kepler considered in accordance with the Tychonic system to be the true ones. I quote the latter from Newton's work *De Mundi Systemate* (*Opuscula math. philos. et philol.* 1744, tom. ii. p. 22):

Planets.	Actual Distances.	Kepler's Results.
Mercury	0·38709	0·38806
Venus	0·72333	0·72400
Earth	1·00000	1·00000
Mars	1·52369	1·52350
Juno	2·66870	
Jupiter	5·20277	5·19650
Saturn	9·53885	9·51000
Uranus	19·18239	
Neptune	30·03628	

sion of the discovery of Pallas by Olbers, aptly criticised the so-called law of distances in a letter to Zach (October, 1802). "The statement of Titius," says he, "contrary to the nature of all truths which merit the name of laws, agrees only approximatively with observed facts in the case of most planets, and, what does not appear to have been once observed, not at all in the case of Mercury. It is evident that the series

$$4,\ 4+3,\ 4+6,\ 4+12,\ 4+48,\ 4+96,\ 4+192,$$

with which the distances should correspond, is not a continuous series at all. The member which precedes $4+3$ should not be 4; *i. e.* $4+0$, but $4+1\frac{1}{2}$. Therefore, between 4 and $4+3$, there should be an infinite number; or, as Wurm expresses it, for $n=1$, there is obtained from $4+2^{n-2}.3$, not 4, but $5\frac{1}{2}$. Otherwise, the attempt to discover such approximative similarities in nature, is by no means to be censured."

5. *Masses of the planets.*—These elements are determined by satellites when there are any, by the mutual disturbances of the principal planets among each other, or by the influence of a comet of brief revolution. In this way the hitherto unknown mass of Mercury was determined by Encke in 1841, by the disturbances which his comet suffered. The same comet offers a prospect of a future improvement in the estimation of the mass of Venus. The disturbances of Vesta are applied to Jupiter. The mass of the Sun being taken as unity, those of the planets are (according to Encke, *vierte Abhandlung über den Cometen von Pons in den Schriften der Berliner Akademie der Wissenschaften* for 1842, p. 5):

Mercury	$\frac{1}{4865751}$
Venus	$\frac{1}{401839}$
Earth	$\frac{1}{359551}$
(Earth and Moon together ...	$\frac{1}{355499}$)
Mars	$\frac{1}{2680337}$
Jupiter and his satellites ...	$\frac{1}{1047.879}$

Saturn	... ...	$\frac{1}{3501 \cdot 6}$
Uranus	... ...	$\frac{1}{24605}$
Neptune	... ...	$\frac{1}{14446}$

The mass $\frac{1}{9322}$, which Le Verrier found by means of his sagacious calculations before the actual discovery of Neptune by Galle is greater, although remarkably near to the truth. The arrangement of the principal planets, according to their increasing masses, is, when leaving out the small ones, the following:

Mercury, Mars, Venus, Earth, Uranus, Neptune, Saturn, Jupiter;

thus like the volumes and densities, entirely different from the order of succession of the distances from the central body.

6. *Densities of the planets.*—By applying the above quoted volumes and masses, the following numerical relations are obtained for the densities of the planets (according as the earth or water is taken as unity):

Planets.	Relation to the Earth.	Relation to the density of Water.
Mercury	1·234	6·71
Venus	0·940	5·11
Earth	1·000	5 44
Mars	0·958	5·21
Jupiter	0·243	1·32
Saturn	0·140	0·76
Uranus	0·178	0·97
Neptune	0·230	1·25

In the comparison of the density of the planets with water, the density of the Earth serves as a basis. Reich's experiments made in Freiberg with the torsion balance, gave 5·4383: very nearly the same as the analogous experiments of Cavendish, which, according to the more accurate calculations of Francis Baily, gave 5·448. The result of Baily's

own experiments is 5·660. It will be seen from the above table, that Mercury, according to Encke's determination of mass, comes very near to the other planets of medium magnitude.

This table calls to mind forcibly the classification, several times mentioned by me, of the planets into two groups, which are separated from each other by the zone of the small planets. The differences of density which are presented by Mars, Venus, the Earth, and even Mercury, are very slight; almost equally similar among each other, but from 4 to 7 times less dense than the former group, are the planets more distant from the Sun,—Jupiter, Neptune, Uranus, and Saturn. The density of the Sun (0·252, if the Earth is taken as 1·000; therefore in reference to water 1·37), is but little more than the densities of Jupiter and Neptune. Consequently, the planets and the Sun[34] must be arranged according to their increasing density, in the following order:

Saturn, Uranus, Neptune, Jupiter, Sun, Venus, Mars, Earth, Mercury.

Although, upon the whole, the densest planets are nearer to the Sun; still, *when they are considered individually*, their density is by no means proportional to the distances, as Newton was inclined to assume.[35]

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[34] The Sun (which Kepler considered to be magnetic, probably from enthusiastic admiration for the *divina inventa* of his justly famous contemporary, William Gilbert, and whose rotation in the same direction as the planets he maintained long before the Sun-spots were discovered), Kepler declares, in his *Comment. de motibus Stellæ Martis* (cap. 23), and in *Astronomiæ pars optica* (cap. 6), to be "the densest of all cosmical bodies; because it moves all the others which belong to his system."

[35] Newton, *De Mundi Systemate*, in *Opusculis*, tom. ii. p. 17: "Corpora Veneris et Mercurii majore Solis calore magis concocta et coagulata sunt. Planetæ ulteriores, defectu caloris, carent substantiis illis metallicis et mineris ponderosis quibus Terra referta est. Densiora corpora quæ Soli propiora: ea

7. *Periods of sidereal revolution and axial rotation.*—We shall confine ourselves here to giving the sidereal, or true periods of revolution of the planets in reference to the fixed stars, or a fixed point of the heavens. During such a revolution, a planet passes through exactly 360 degrees in its course round the Sun. The sidereal revolutions of the planets must be clearly distinguished from the tropical and synodic, the former of which refer to the return to the spring equinox, the latter to the difference of time between two consecutive conjunctions or oppositions.

Planets	Periods of sidereal Revolutions.	Rotation.
		d h m s
Mercury	$87^{d}\cdot96928$	
Venus	224·70078	
Earth	365·25637	0 23 56 4
Mars	686·97964	1 0 37 20
Jupiter	4332·58480	0 9 55 27
Saturn	10759·21981	0 10 29 17
Uranus	30686·82051	
Neptune	60126·70000	

In another more perspicuous form the two periods of revolution are:—

Mercury	87^{d}	23^{h}	15^{m}	47^{s}
Venus	224	16	49	7
Earth	365	6	9	10·7496:

ratione constabit optime pondera Planetarum omnium esse inter se ut vires."—"The bodies of Venus and Mercury are more ripened and condensed, on account of the greater heat of the Sun. The more remote planets, by want of heat, are deficient in those metallic substances and weighty minerals with which the Earth abounds. Bodies are denser in proportion to their nearness to the Sun,—from which reason it will easily appear that the weight of all planets is in proportion to their forces."

whence it follows that the period of the tropical revolution, or the length of the solar year, is $365^{d} \cdot 24222$, or 365d. 5h. 48m. $47^{s} \cdot 8091$; the length of the solar year is shortened $0'' \cdot 595$ in 100 years on account of the precession of the equinoxes:—

Mars	1 year,	321^{d}	17^{h}	30^{m}	41^{s}
Jupiter ...	11 years,	314	20	2	7
Saturn... ...	29 years,	166	23	16	32
Uranus	84 years,	5	19	41	36
Neptune ...	164 years,	225	17	0	0

The rotation is most rapid in the case of the exterior planets, which have at the same time a longer period of revolution; slower in the case of the smaller interior planets, which are nearer to the Sun. The periods of revolution of the asteroids between Mars and Jupiter are very various, and will be spoken of in the enumeration of the individual planets. It is, therefore, sufficient in this place to give a comparative result, and to observe that among the small planets, Hygeia has the longest, and Flora the shortest period of revolution.

8. *Inclination of the planetary orbits and axes of rotation.*—Next to the masses of the planets, the inclination and eccentricity of their orbits are among the most important elements upon which the disturbances depend. The comparison of these, in the order of succession of the interior, small intermediate and exterior planets (from Mercury to Mars, from Flora to Hygeia, from Jupiter to Neptune), presents manifold similarities and contrasts, which lead to considerations as to the formation of these cosmical bodies, and their changes during long periods of time. The planets revolving in such various elliptical orbits, are also all situated in different planes. In order to render a numerical comparison possible, they are reduced to a fundamental plane, either fixed or moveable, according to certain laws. As such the most convenient is the ecliptic—the course which the Earth actually traverses—or the equator of the terrestrial spheroid. We

add to the same table, the inclinations of the axes of rotation of the planets towards their own orbits, so far as they are determined with any certainty.

Planets.	Inclination of the Planetary Orbits to the Ecliptic.	Inclination of the Planetary Orbits to the Earth's Equator.	Inclination of the axes of the Planets to their Orbits.
Mercury ...	7° 0′ 5″·9	28° 45′ 8″	
Venus ..	3° 23′ 28″·5	24° 33′ 21″	
Earth ...	0° 0′ 0″	23° 27′ 54″·8	66° 32′
Mars ...	1° 51′ 6″·2	24° 44′ 24″	61° 18′
Jupiter ...	1° 18′ 51″ 6	23° 18′ 28″	86° 54′
Saturn ...	2° 29′ 35″·9	22° 38′ 14″	
Uranus ...	0° 46′ 28″·0	23° 41′ 24″	
Neptune ...	1° 47′ 0″	22° 21′ 0″	

The small planets are omitted here, because they will be treated of further on as a separate distinct group. If we except Mercury, situated near the Sun, and the inclination of whose axis towards the ecliptic (7° 0′ 5″·9) approaches very near to that of the solar equator (7° 30′) the inclinations of the other seven planets will be seen to oscillate between 0¾° and 3⅓°. Jupiter exhibits, in the position of the axis of rotation with reference to its own orbit, the closest approximation to the extreme of perpendicularity. On the contrary, the axis of rotation of Uranus, to conclude from the inclination of the orbits of its satellites, very nearly coincides with the plane of the planet's orbit.

Since the division and duration of the seasons, the solar altitudes under various latitudes, and the length of the days, depend upon the amount of the inclination of the Earth's axis towards the plane of its orbit, as well as upon the obliquity of the ecliptic (*i. e.* upon the angle which the apparent course of the Sun makes with the equator at their point of intersection), this element is of the most extreme importance as regards the astronomical climate, *i. e.* the temperature of the

Earth, in as far as this is a function of the meridian altitude attained by the Sun and the duration of its continuance above the horizon. If the obliquity of the ecliptic were great, or if, indeed, the Earth's equator were perpendicular to the Earth's orbit, at each part of its surface, even under the poles, the Sun would be in the zenith once in the year, and, for a greater or less time, neither rise nor set. The differences of summer and winter under each latitude (as well as the length of the day), would attain the maximum of opposition. The climates in each part of the Earth would belong, in the highest degree, to those which are called extreme, and which an interminably complicated series of rapidly changing currents of air could only slightly equalize. If the reverse were the case, or the obliquity of the ecliptic null, if the Earth's equator coincided with the ecliptic, the differences of the seasons and in the length of the days would cease everywhere, because the Sun would continually appear to move in the equator. The inhabitants of the poles would see it perpetually at the horizon. "The mean annual temperature of each point of the Earth's surface, would also be that of each individual day."[36] This condition has been called an eternal spring, although, however, only on account of the universally equal length of the days and nights. As the growth of plants would be deprived of the stimulating action of the Sun's heat, a great part of those districts which we now call temperate zones, would be reduced to the almost always uniform and not very agreeable spring climate, from which I suffered much under the equator, upon the barren mountain plains (Paramos[37]) between 10,659 and 12,837 feet above the level of the sea, situated near the boundary of

[36] Mädler, *Astronomie.* § 193.
[37] Humboldt, *De Distributione geographica Plantarum*, p. 104. (*Views of Nature*, p. 220 to 223, Bohn's edition.)

perpetual snow in the Andes chain. The temperature of the air during the day oscillates there between 4°½ and 9° Réaum. (42° and 52°·25 Fahr.)

Grecian antiquity was much occupied with the obliquity of the ecliptic, with rough measurements, conjectures as to its variability, and the influence of the inclination of the Earth's axis upon climate, and the luxuriance of organic development. These speculations belonged especially to Anaxagoras, the Pythagorean school, and to Œnopides of Chios. The passages which give us any information on this point are scanty and indecisive; however, they show that the development of organic life and the origin of animals were considered to have been simultaneous with the epoch in which the axis of the Earth first commenced to be inclined, which also altered the inhabitability of the planet in particular zones. According to Plutarch, *De Plac. Philos.* ii. 8, Anaxagoras believed "that the world, after it had come into existence and produced from its womb living beings, had of itself inclined towards the south." In the same regard, Diogenes Laertius says of the Clazomenier, "the stars had originally projected themselves in a dome-like layer, so that the pole appearing at any time was vertically over the Earth; but that afterwards they assumed an oblique direction." The origin of the obliquity of the ecliptic was considered as a cosmical *event*. There was no question respecting a subsequent progressive alteration.

The description of the two extreme, therefore opposite, conditions to which the planets Uranus and Jupiter approximate most closely, is suited to call to mind the variations which the *increasing* or *decreasing* obliquity of the ecliptic would produce in the meteorological relations of our planet, if these variations were not comprised within *very narrow limits*. The knowledge of these limits, the subject of the great works of Leonhard Euler, Lagrange, and Laplace, may

be called one of the most brilliant achievements of modern times in theoretical astronomy and the perfected higher analysis. These limits are so narrow, that Laplace (*Expos. du Système du Monde*, ed. 1824, p. 303,) puts forward the opinion that the obliquity of the ecliptic oscillates about its mean position only 1½° towards both sides. According to this statement,[28] the tropical zone (the tropic of Cancer, as its northernmost and outermost boundary) would approach only so much nearer to us. The result would therefore be, if the numerous other meteorological perturbations are omitted, as if Berlin were gradually displaced from its present isothermal line to that of Prague. The elevation of the mean annual temperature would scarcely amount to more than one degree of the centigrade ($\frac{8}{10}$ of a degree of Fahrenheit's) thermometer.[29] Biot, indeed, also assumes only narrow limits for the alternating variation in the obliquity of the ecliptic, but considers it more advisable not to assign to it a determinate number. "La diminution lente et séculaire de l'obliquité de l'écliptique," says he, "offre des états alternatifs qui produisent une oscillation éternelle, comprise entre des limites fixes. La théorie n'a pas encore pu parvenir à déterminer ces limites; mais d'après la constitu-

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[28] "L'étendue entière de cette variation serait d'environ 12 degrés, mais l'action du Soleil et de la Lune la réduit à peu près à trois degrés (centésimaux)." "The entire extent of that variation would be about 12 degrees, but the action of the Sun and Moon reduce it to very nearly 3 degrees (centesimal)."—Laplace, *Expos. du Syst. du Monde*, p. 303.

[29] I have shown in another place, by comparison of numerous mean annual temperatures, that in Europe, from the North Cape to Palermo, the difference of one degree of geographical latitude very nearly corresponds to 0·5° of the centigrade thermometer, but in the western temperature-system of America (between Boston and Charlestown) to 0·9°. (*Asie Centrale*, tom. iii. p. 229.)

tion du système planétaire, elle a démontré qu'elles existent et qu'elles sont *très peu étendues*. Ainsi, à ne considérer que le seul effet des causes constantes qui agissent actuellement sur le système du monde, on peut affirmer que le plan de l'écliptique *n'a jamais coincidé* et ne *coincidera jamais* avec le plan de l'équateur, phénomène qui, s'il arrivait, produirait sur le Terre le (prétendu!) printemps perpétuel."*—Biot, *Traité d'Astronomie Physique*, 3rd ed. 1847, tom. iv. p. 91.

While the nutation of the Earth's axis discovered by Bradley depends merely upon the influence of the Sun and the Earth's satellite upon the oblate figure of our planet, the increase and decrease in the obliquity of the ecliptic is the consequence of the variable position of all the planets. At the present time these are so situated that their united influence upon the Earth's orbit produces a diminution in the obliquity of the ecliptic. This obliquity amounts, according to Bessel, to 0″·457 annually. At the end of many thousand years the situation of the planetary orbits and their nodes (their points of intersection with the ecliptic) will be so different, that the advance of the equinoxes will be converted into a retrogression, and consequently an increase in the obliquity of the ecliptic. Theory teaches us that these increases and diminutions occupy periods of very unequal duration. The most ancient astronomical observations which

* "The slight and secular variation of the obliquity of the ecliptic presents alternating states which produce an eternal oscillation comprised within fixed limits. Theory has not been able to determine those limits; but according to the constitution of the planetary system it has been proved that they exist, and that they are of *very slight extent*. Thus, to consider only the effect of the permanent causes which act upon the system of the world, it may be affirmed that the plane of the ecliptic *never has and never will* coincide with the plane of the equator, a phenomenon which, if it took place, would produce upon the Earth the (pretended!) eternal spring.

have come down to us, with accurate numerical data, reach back to the year 1104 before Christ, and testify to the extreme antiquity of Chinese civilization. The literary remains are scarcely a century more recent, and a regulated calculation of time extends (according to Edward Biot) as far back as 2700 years before Christ.[40] Under the reign of Tscheu-Kung, the brother of Wu-Wang, the meridian shadows were measured in two solstices, upon an eight-foot gnomon, in the town of Layang, south of the Yellow River (the town is now called Ho-nan-fu and is in the province of Ho-nan), in a latitude of of 34° 46′.[41] These measurements gave the obliquity of the ecliptic as 23° 54′; that is, 27′ greater than it was in 1850. The observations of Pytheas and Eratosthenes at Marseilles and Alexandria are six and seven centuries later. We possess the results of four observations of the obliquity of the ecliptic previous to our era, and seven subsequent, up to Ulugh Beg's observations at the observatory of Samarcand. The theory of Laplace corresponds sometimes in plus, sometimes in minus, in an admirable manner with the observations made during a period of nearly 3000 years. The knowledge transmitted to us of Tscheu-Kung's measurement of the shadow-length is so much the more fortunate as the manuscript which mentions it escaped, from some unknown cause, the fanatical destruction of books commanded by the Emperor Schi-hoang-ti of the Tsin dynasty, in the year 246 before Christ. Since the commencement of the fourth Egyptian dynasty with the Kings Chufu, Schafra, and Menkera,—the builders of the Pyramids,—falls, according to Lepsius, twenty-three centuries before the solstitial observation at Layang,

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[40] *Cosmos*, vol. ii. p. 475, 476, and note.

[41] Laplace, *Expos. du Système du Monde*, 5th ed. p. 303, 345, 403, 406, and 408; the same in the *Connaissance des Temps pour* 1811, p. 386; Biot, *Traité Elém. d'Astron. Physique*, tom. i. p. 61; tom. iv. p. 90–99, and 614–623.

it is indeed very probable, from the high degree of civilization of the Egyptian people and their early regulation of a calendar, that even at that time the length of shadows had been measured in the valley of the Nile; but no knowledge of this has come down to us. Even the Peruvians, although less advanced in the perfection of calendars and intercalations than the Muyscas (mountain inhabitants of New Granada) and the Mexicans were, possessed gnomons, surrounded by a circle marked upon a very level surface. They stood in several parts of the empire, as well as in the great temple of the Sun at Cuzco; the gnomon at Quito, situated almost under the equator, was held in greater veneration than the others, and crowned with flowers upon the equinoctial feasts.*

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* Garcilaso, *Comment. Reales*, part i. lib. ii. cap. 22–25; Prescott, *Hist. of the Conquest of Peru*, vol. i. p. 126. The Mexicans possessed among their twenty hieroglyphical signs of the days, one held in especial veneration called *Ollintonatiuh*, that of the *four movements of the Sun*, which governed the great cycle, renewed every $52 = 4 \times 13$ years, and referred to the course of the Sun intersecting the solstices and equinoxes, and hieroglyphically expressed by *foot-steps*. In the beautifully-painted illuminated Aztec manuscript, which was formerly preserved in the villa of Cardinal Borgia at Veletri, and from which I derived much important information, there is the remarkable astrological sign of a cross, the day signs which are written on the margin by its side would perfectly represent the passage of the Sun through the zenith of the town of Mexico (Tenochtitlan), the equator and the solstitial points, if the points (round discs) added to the *day signs* on account of the periodic series, were equally complete in all *three* passages of the Sun. (Humboldt, *Vues des Cordillères*, pl. xxxvii. No. 8, pp. 164, 189 and 237.) The King of Tezcuco, Nezahualpilli (called a *fast child*, because his father fasted for a long time previously to the birth of the wished-for son) who was passionately given to astronomical observations, erected a building which Torquemada rather venturously calls an *observatory*, and the ruins of

9. *Excentricity of the Planetary Orbits.*—The form of the elliptical orbits is determined by the greater or less distance of the two foci from the centre of the ellipse. This distance, or the *excentricity* of the planetary orbits expressed in fractional parts of their half major axes, varies from 0·006 in the orbit of Venus (consequently very near the circular form), and 0·076 in that of Ceres, to 0·205 and 0·255 in those of Mercury and Juno. Next in succession to the least excentric orbits of Venus and Neptune follows that of the Earth, whose excentricity is now decreasing at the rate of about 0·00004299 in 100 years, while the minor axis increases; then come the orbits of Uranus, Jupiter, Saturn, Ceres, Egeria, Vesta, and Mars. The most excentric orbits are those of Juno (0·255), Pallas (0·239), Iris (0·232), Victoria (0·217), Mercury (0·205), and Hebe (0·202). The excentricity is on the increase in the orbits of some planets, as Mercury, Mars, and Jupiter; on the decrease in those of others, as Venus, the Earth, Saturn, and Uranus. The following table gives the excentricities of the large planets for the year 1800, according to Hansen. The excentricities of the *fourteen small planets* will be given subsequently, together with other elements of their orbits for the middle of the nineteenth century.

Mercury	0·2056163
Venus	0·0068618
Earth	0·0167922
Mars	0·0932166
Jupiter	0·0481621
Saturn	0·0561505

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which he saw. (*Monarquia Indiana*, lib. ii. cap. 64.) In the *Raccolta di Mendoza*, we find a priest represented (*Vues des Cordillères*, pl. lviii. No. 8, p. 289), who is watching the stars, which is expressed by a dotted line which passes from the observed star to his eye.

Uranus .. .. 0·0466108
Neptune .. .. 0·00871946

The *motion of the major axis* (*line of apsides*) of the planetary orbits by which the place of the perihelion is changed, is a motion which goes on perpetually in one direction, and proportionally to the time. It is a change in the *position* of the major axis, which requires more than a hundred thousand years to complete its cycle, and is to be distinguished as essentially different from those alterations which the planetary orbits undergo in their *form*—their ellipticity. The question has been raised as to whether the increasing value of this ellipticity, is capable during thousands of years of modifying, to any considerable extent, the temperature of the Earth, in reference to the daily and annual *quantity* and *distribution* of heat? Whether a partial solution of the great geological problem of the embedding of tropical vegetable and animal remains in the now cold zones may not be found in these *astronomical* causes proceeding *regularly* in accordance with eternal laws? The same mathematical arguments which excite apprehensions as to the position of the apsides, the form of the elliptical planetary orbits (according as these approach the circular form or a cometary eccentricity), as to the inclination of the planetary axes, changes in the obliquity of the ecliptic, the influence of precession upon the length of the year, also afford in their higher analytical development, cosmical grounds for reassurance. The *major axes* and the *masses* are constant. *Periodic recurrence* hinders *the unlimited augmentation* of certain perturbations. In consequence of the mutual and at the same time compensating influence of Jupiter and Saturn, the excentricities of their orbits, in themselves slight, are alternately in a state of increase and decrease, and are also comprised within fixed and for the most part narrow limits.

The point in which the Earth is nearest to the Sun falls in

very different periods of the year, in consequence of the alteration in the *position* of the major axis.[43] If the perihelion falls at the present time on the first day of January, and the aphelion six months afterwards, upon the first day of July, it may happen on account of the advance (*turning*) of the major axis of the Earth's orbit, that the minimum may occur in summer and the maximum in winter, so that in January the Earth would be farther from the Sun than in the summer, by about 2,800,000 geographical miles (*i. e.* about $\frac{1}{30}$th of the mean distance of the Earth from the Sun). It might at the first glance be supposed that the occurrence of the *perihelion* at an opposite time of the year (instead of the winter, as is now the case, in summer), must necessarily produce great climatic variations; but, on the above supposition, the Sun will no longer remain seven days longer in the northern hemisphere; no longer, as is now the case, traverse that part of the ecliptic from the autumnal equinox to the vernal equinox, in a space of time which is one week shorter than that in which it traverses the other half of its orbit from the vernal to the autumnal equinox. The difference of temperature which is considered as the consequence to be apprehended from the turning of the major axis (and we refer here merely to the *astronomical climates*, excluding all considerations as to the relations of the solid and liquid portion of the many-formed surface of the Earth), will, on the whole, disappear,[44] principally from the circumstance that the point of our planet's orbit in which it is *nearest* to the Sun is at the same time always that over which it passes with the

[43] John Herschel *on the Astronomical Causes which may influence Geological Phenomena*, in the *Transact. of the Geolog. Soc. of London*, 2nd series, vol. iii. pl. i. p. 298; the same in his *Treatise on Astronomy*, 1833. (*Cab. Cyclop.* vol. xliii. § 315.)

[44] Arago, in the *Annuaire* for 1834, p. 199.

greatest velocity. The reassuring solution of this problem is to a certain extent contained in the beautiful law first pointed out by Lambert,[45] according to which the quantity of heat which the Earth receives from the Sun in each part of the year, is proportional to the angle which the *radius vector* of the Sun describes during the same period.

As the altered position of the major axis is capable of exerting only a very slight influence upon the temperature of the Earth; so likewise the *limits* of the probable changes in the elliptical form of the Earth's orbit are, according to Arago and Poisson,[46] so narrow that these changes could only very

[45] "Il s'ensuit (du théorème dû à Lambert) que la quantité de chaleur envoyée par le Soleil à la Terre est la même en allant de l'équinoxe du printems à l'équinoxe d'automne qu'en revenant de celui-ci au premier. Le tems plus long que le Soleil emploie dans le premier trajet, est exactement compensé par son éloignement aussi plus grand; et les quantités de chaleur qu'il envoie à la Terre, sont les mêmes pendant qu'il se trouve dans l'un ou l'autre hémisphere, boréal ou austral."—Poisson, *Sur la Stabilité du Système Planétaire*, *Connaissance des Temps* for 1836, p. 54. "It follows from the theorem of Lambert, that the quantity of heat which is conveyed by the Sun to the Earth is the same during the passage from the vernal to the autumnal equinox as in returning from the latter to the former. The much longer time which the Sun takes in the first part of its course, is exactly compensated by its proportionately greater distance, and the quantities of heat which it conveys to the Earth are the same while in the one hemisphere or the other, north or south."

[46] Arago, *op. cit.* pp. 300–204. "L'excentricité," says Poisson, (*op. cit.* pp. 38 and 52,) "ayant toujours été et devant toujours demeurer très petite, l'influence des variations séculaires de la quantité de chaleur solaire reçue par la Terre sur la température moyenne parait aussi devoir être très limitée. On ne saurait admettre que l'excentricité de la Terre, qui est actuellement environ un soixantième, ait jamais été ou devienne jamais un quart, comme celle de Junon ou

slightly modify the climates of the individual zones, and that in very long periods. Although the analyses which determine these limits accurately is not yet quite completed, still so much, at least, follows from it, that the excentricity of the Earth's orbit will never equal those of the orbits of Juno, Pallas, and Victoria.

10. *Intensity of the Light of the Sun upon the Planets.*—If the intensity of light upon the Earth is taken as =1, it will be found to be upon the other planets, as follows:—

Mercury	6·674
Venus	1·911
Mars	0·431
Pallas	0·130
Jupiter	0 036
Saturn	0·011
Uranus	0 003
Neptune...	0·001

In consequence of the very great excentricity of their orbits, the intensity of light on the following planets varies in—

Mercury,	in perihelion,	10·58;	in aphelion,	4·59
Mars	,, ,,	0·52;	,, ,,	0·36
Juno	,, ,,	0·25;	,, ,,	0·09

while the Earth, owing to the slight excentricity of its orbits, has in perihelion 1·034, and in aphelion 0·967. If the Sunlight upon Mercury is seven times more intense than upon

de Pallas." "As the excentricity always has been, and always will be, very small, the influence of the secular variations of the quantity of solar heat received by the Earth upon the mean temperature would appear also to be very limited. It cannot be admitted that the excentricity of the Earth, which is actually about $\frac{1}{60}$, has ever been, or ever will be $\frac{1}{4}$ as that of Juno or Pallas."

the Earth, it must also be 368 times more feeble upon Uranus. The *relations of heat* have not been mentioned here, because they are complicated phenomena, dependent upon the existence or non-existence of an atmosphere surrounding the planets, its constitution, and height. I will merely call to mind here the conjecture of Sir John Herschel, as to the temperature of the Moon's surface, "which must necessarily be very much heated,—*possibly* to a degree much exceeding that of boiling water."[47]

b. SECONDARY PLANETS.

The *general comparative considerations* relating to the secondary planets, have already been given with some completeness in the *delineations of nature.* (*Cosmos*, vol i. pp. 79–83.) At that time (March, 1845,) there were only 11 principal, and 18 secondary planets known. Of the asteroids, so called *telescopic*, or small planets, only 4 were discovered: Ceres, Pallas, Juno, and Vesta. At the present time (August, 1851,) the number of the *principal planets* exceeds that of the *satellites.* We are acquainted with 22 of the former, and 21 of the latter. After an intermission of thirty-eight years in planetary discoveries (from 1807, to December, 1845), commenced a long series of 10 new small planets, with Astrea, discovered by Hencke. Of these, 2 (Astrea and Hebe) were first detected by Hencke at Driesen, 4 (Iris, Flora, Victoria, and Irene) by Hind in London, 1 (Metis) by Graham at Markree Castle, and 3 (Hygeia, Parthenope, and Egeria) by De Gasparis at Naples. The discovery of the outermost of all the large planets, Neptune, announced by Leverrier, and found by Galle at Berlin, followed ten months after Astrea. The discoveries now accumulate with such

[47] *Outlines*, § 432.

rapidity, that the topography of the solar regions appears after the lapse of a few years, quite as antiquated as statistical descriptions of countries.

Of the 21 satellites now known, 1 belongs to the Earth, 4 to Jupiter, 8 to Saturn (the last discovered of these 8 is, according to distance, the seventh, Hyperion: discovered in two different places at the same time by Bond and Lassell), 6 to Uranus (of which the second and fourth are most positively determined), and 2 to Neptune.

The satellites revolving round the principal planets constitute *subordinate systems*, in which the principal planets take the place of central bodies, forming individual regions of very different dimensions, in which the great solar region is, as it were, repeated in miniature. According to our present knowledge, the region of Jupiter is 2,080,000 geographical miles in diameter, and that of Saturn 4,200,000. In Galileo's time, when the expression of a small *Jovial world* (*Mundus Jovialis*) was frequently made use of, these analogies between the subordinate systems and the solar system, contributed much to the more rapid and general diffusion of the Copernican system of the world. They suggest the repetitions of form and position which is so frequently presented by organic nature in subordinate spheres.

The distribution of the satellites in the solar regions is so unequal, that while the proportion of the moonless principal planets, to those which are accompanied by Moons, is as 3 to 5, the latter belong, with the single exception of one, the Earth, to the *exterior planetary groups*, situated beyond the ring of the asteroids with interlacing orbits. The only satellite which has been formed in the group of interior planets between the Sun and the asteroids, the *Earth's Moon*, has a remarkably large diameter in proportion to that of its primary. This proportion is $\frac{1}{3\cdot8}$: while the largest of Saturn's satellites (the sixth, Titan), is perhaps only $\frac{1}{15\cdot8}$; and the

largest of Jupiter's satellites, the third, $\frac{1}{25 \cdot 8}$ of the diameter of their primaries. A wide distinction must be drawn between this consideration of a relative magnitude, and that of an absolute magnitude. The Earth's Moon, relatively so large (1816 miles in diameter), is absolutely smaller than all four of Jupiter's satellites (3104, 2654, 2116, and 1900 miles in diameter). The sixth satellite of Saturn differs very little in magnitude from Mars (3568 miles).[48] If the problem of telescopic visibility depended only upon the diameter, and was not at the same time determined by the proximity of the discs of the primaries, the great distance and the nature of the reflecting surfaces, it would be necessary to consider as the smallest of the secondary planets, the first and second of Saturn's satellites (Mimas and Enceladus), and the two satellites of Uranus; but it is safer to represent them merely as the smallest luminous points. It has hitherto appeared more certain that upon the whole, the smallest of all planetary bodies (primaries and satellites), are to be found among the small planets.[49]

The density of the satellites is by no means always *less* than that of their primaries, as is the case with the Earth's Moon (whose density is only 0·619 of that of our Earth) and the third satellite of Jupiter. The densest of this group of satellites, the second, is even *denser* than Jupiter himself, while the third and largest appears to be of *equal* density with the primary. The masses also do not increase in at all the same ratio as the distances. If the planets have been formed from revolving rings, then the greater or less dense aggregation round a nucleus must have been caused by

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[48] *Outlines*, § 548.

[49] See Mädler's attempt to estimate the diameter of Vesta (264 geographical miles) with a thousand-fold magnifying power in his *Astronomie*, p. 218.

peculiar causes, which may, perhaps, always remain unknown to us.

The orbits of the secondary planets which belong to the same group, have very different degrees of excentricity. In the Jovial system, the orbits of the first and second satellites are nearly circular, while the excentricities of those of the third and fourth satellites amount to 0·0013 and 0·0072. In the Saturnian system, the orbit of the satellite nearest to the primary (Mimas), is considerably more excentric than the orbits of Enceladus and Titan, the largest and first discovered, whose orbit was so accurately determined by Bessel. The excentricity of the orbit of the sixth satellite of Saturn, is only 0·02922. According to all these data, which are among those that may be relied upon, Mimas only is more excentric than the Earth's Moon (0·05484); the latter possesses the peculiarity that its orbit round the Earth has a greater excentricity, in comparison with that of its primary, than any other satellite. Mimas revolves round Saturn in an orbit whose excentricity is 0·068, while that of the orbit of its primary is 0·056; but the orbit of our Moon has an excentricity of 0·054, while the excentricity of that of the Earth is only 0·016. With regard to the distances of the satellites from their primaries, compare *Cosmos*, vol. i. pp. 78–83. The distance of the satellite nearest to Saturn (Mimas), is now no longer taken as 80,088 geographical miles, but as 102,400; whence its distance from the ring, this being calculated as 24,188 miles broad, and at a distance of 18,376 miles from the surface of the planet, will be 28,000 miles.[*] Remarkable anomalies, together with a certain correspondence, are also presented in the position of the orbits of the satellites in the Jovial system, in which very

[*] In the earlier data (*Cosmos*, vol. i. p. 82) the equatorial diameter was taken as a basis.

nearly all the satellites move in the plane of the equator of their primary. In the group of Saturnian satellites, seven of them revolve almost in the plane of the ring, while the outermost (the eighth, Japetus) is inclined towards their plane 12° 14′.

In this general consideration of the planetary revolutions in the universe, we have descended from the higher,—though probably not the highest[a] system,—from that of the Sun to the subordinate partial systems of Jupiter, Saturn, Uranus, and Neptune. In the same way that from the striving towards generalization of views, which is innate in thoughtful, and at the same time imaginative men, the unsatisfied cosmical presentiment of a translatory motion[aa] of our solar system through space, appears to suggest the idea of a higher relation and subordination; so the possibility has been conceived that the satellites of Jupiter may be again central bodies to other secondary ones, which, on account of their smallness, are unseen. In that case the individual members of the partial systems, which are chiefly situated among the group of exterior principal planets, would have other and similar partial systems subordinate to them. Repetitions of form in recurring organizations, as well as the self-created images of the fancy, are certainly pleasing to a systematic mind; but in every serious investigation, it is imperatively necessary to distinguish between the ideal and the actual Cosmos; between the possible, and that which has been discovered by actual observation.

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[a] Compare *Cosmos*, vol. iii. p. 267.

[aa] I have fully treated of the translatory motion of the Sun in the delineation of nature. (*Cosmos*, vol. i. pp. 134–139. Compare also vol. iii. p. 251.)

SPECIAL ENUMERATION OF THE PLANETS AND THEIR MOONS, AS PARTS OF THE SOLAR SYSTEM.

It is, as I have already often remarked, the especial object of a *physical description of the world*, to bring together all the important and well-established numerical results which have been obtained in the domain either of *sidereal* or *terrestrial* phenomena up to the middle of the nineteenth century. All that has form and motion should here be represented as something *already created*, *existing*, and *definite*. The grounds upon which the obtained numerical results are founded; the cosmological conjectures respecting *genetic developement*, which during thousands of years have been called into existence by the ever-changing conditions of mechanical and physical knowledge:—these do not, in the strictest sense of the word, come within the range of *empirical* investigation. (*Cosmos*, vol. i. pp. 27–29, 54, and 67.)

The Sun.

Whatever relates to the dimensions, or to the present views as to the physical constitution of the central body, has been already given. (*Cosmos*, vol. iv. pp. 359–401.) It only remains to add in this place some remarks, according to the most recent observations, upon the *red figures* and *masses of red clouds*, which were specially treated of at page 374. The important phenomena which the total eclipse of the Sun of July 28, 1851, presented in Eastern Europe, have still more strengthened the opinion put forward by Arago, in 1842, that the red mountain—or cloud-like *projections* upon the edge of the

eclipsed Sun, belong to the outermost gaseous envelope of the central body.[1] These projections became visible on the Moon's western edge as it proceeded in its motion towards the east (*Annuaire du Bureau des Longitudes* for 1842, p. 457); and disappeared again when they were *covered* on the opposite by the eastern edge of the Moon.

On a subsequent occasion the intensity of the light of these projections became so considerable, that they could be perceived within the corona through telescopes, when veiled by their clouds, and even with the naked eye.

The form of some of the projections, which were mostly ruby or peach-coloured, changed with perceptible rapidity during the total obscuration; one of these projections appeared to be curved at its summit, and presented to many observers the appearance of a freely suspended detached *cloud*,[2] near the point, and resembling a column of smoke curved back at the top. The height of most of these projections was estimated at from 1′ to 2.; at one point it is said to have been more. Besides these tap-formed projections, from three to five of which were counted, there were also observed riband-like streaks of a carmine colour, extended lengthways, which appeared to rest upon the Moon, and were often serrated.[3]

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[1] *Cosmos*, vol. iii. p. 388. Notes 19 and 20.

[2] Compare the observations of the Swedish mathematician, Bigerus Vassenius, at Gottenburg, during the total eclipse of May 2, 1733, and the commentary upon them by Arago, in the *Annuaire du Bureau des Longitudes*, for 1846, pp. 441 and 462. Dr. Galle, who observed on the 28th of July at Frauenburg, saw "the freely suspended cloud connected with the curved, hook-formed gibbosity by three or more threads."

[3] Compare what a very expert observer, Captain Bérard, saw at Toulon upon the 8th of July, 1842. "Il vit une bande rouge très mince, dentelée irrégulièrement." (*Annuaire du Bureau des Longitudes*, p 416.) "He saw a very narrow red band irregularly serrated."

That part of the Moon's edge which was not projected upon the Sun's disc again became perceptible, especially during the egress.[4]

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[4] This outline of the Moon, clearly perceived by four observers during the total eclipse of the Sun on the 8th of July, 1842, was never previously described as having been seen during similar eclipses. The possibility of seeing an exterior outline, appears to depend upon the light which is given by the third outermost envelope of the Sun and the ring of light (corona). "La Lune se projette *en partie* sur l'atmosphere du Soleil. Dans la portion de la lunette où l'image de la Lune se forme, il n'y a que la lumière provenant de l'atmosphère terrestre. La Lune ne fournit rien de sensible, et, semblable à un écran, elle arrête tout ce qui provient de plus loin et lui correspond. En dehors de cette image, et précisément à partir de son bord, le champ est éclairé *à la fois* par la lumière de l'atmosphère terrestre et par la *lumière de l'atmosphère solaire.* Supposons que ces deux lumières réunies forment un total plus fort de $\frac{1}{60}$ que la lumière atmosphérique terrestre, et, dès ce moment, le bord de la Lune sera visible. Ce genre de vision peut prendre le nom de *vision negative;* c'est en effet par une *moindre intensité* de la portion du champ de la lunette où existe l'image de la Lune, que le *coutour* de cette image est aperçu. Si l'image était *plus intense* que le reste du champ, la vision serait positive."—Arago, *Annuaire du Bureau des Longitudes*, p. 384. "The Moon is projected *partially* upon the atmosphere of the Sun. In that portion of the telescope where the image of the Moon is formed, no other light enters except that of the terrestrial atmosphere. The Moon gives no sensible light, and like a screen, it stops all that which comes from beyond and corresponds with it. Outside the image, and immediately round its edge, the field is lighted *simultaneously* by the light of the terrestrial atmosphere, and by *that of the solar atmosphere.* If we suppose that these two lights collectively, are $\frac{1}{60}$ stronger than the light of the terrestrial atmosphere, the Moon's edge will be directly visible. This kind of vision may be designated a *negative vision*, for it is in fact by the *less intensity* of that portion of the field of the telescope in which is the image of the

A group of Sun-spots was visible, though some minutes distant from the edge of the Sun, where the largest red, hook-formed projection was developed. On the opposite side, not far from the feeble eastern projection, there was also a Sun-spot near the edge. It is scarcely possible that these funnel-shaped depressions can have furnished the material constituting the red gaseous exhalations, on account of the distance above-mentioned; but as the whole surface of the Sun appears to be covered with pores, perhaps the most probable conjecture is, that the same emanation of vapour and gas, which rising from the body of the Sun forms the funnels,[5] pours through these which appear to us as Sun-spots, or smaller pores, and when illuminated present the appearance of red columns of vapour, and clouds of various forms in the third envelope of the Sun.

Mercury.

When it is remembered how much the Egyptians[6] occupied themselves with the planet Mercury (Set-Horus), and the Indians with their Buddha,[7] since the earliest times; how, under the clear heaven of Western Arabia, the star-worship of the race of the Asedites[8] was exclusively directed to Mercury; and, moreover, that Ptolemy was able, in the 19th book of the *Almagest*, to make use of fourteen observations of this planet, which reach back to 261 years before our era,

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Moon, that the outline of this image is perceptible. If this image were more intense than the remaining part of the field, the vision would be positive." (Compare also on this subject, *Cosmos*, vol. iii. p. 71. Note 19.)

[5] *Cosmos*, vol. iv. pp. 365–371.

[6] Lepsius, *Chronologie der Ægypter*, Th. i. pp. 92–96.

[7] *Cosmos*, vol. iv. p. 410, note 13.

[8] *Cosmos*, vol. ii. p. 592.

and partly belong to the Chaldeans;[9] it is certainly astonishing that Copernicus, who had reached his seventieth year, should have lamented, when on his death-bed, that with all his endeavours, he had never seen Mercury. Still the Greeks[10] justly characterized this planet by the name of (στίλβων) the sparkling, on account of its occasionally very intense light. It presents phases (variable form of the illuminated part of the disc) the same as Venus, and, like the latter, appears to us as a morning and evening star.

Mercury is, in his mean distance, little more than 32 millions of geographical miles from the Sun, exactly 0·3870938 parts of the mean distance of the Earth from the Sun. On account of the great excentricity of his orbit (0·2056163) the distance of Mercury from the Sun in perihelion is 25 millions, in aphelion 40 millions of miles. He completes his revolution round the Sun in 87 mean terrestrial days and 23h. 15m. 46s. Schröter and Harding have estimated the rotation at 24h. 5m. from the uncertain observation of the form of the southern cusp of the crescent, and from the discovery of a dark streak, which was darkest towards the east.

According to Bessel's determination on the occasion of the transit of Mercury on May 5, 1832, the true diameter amounts to 2,684 geographical miles,[11] *i. e.* 0·391 parts of the Earth's diameter.

[9] Lalande, in the *Mém. de l'Acad. des Sciences* for 1766, p. 498; Delambre, *Histoire de l'Astron. ancienne*, tom. ii. p. 320.

[10] *Cosmos*, vol. iv. p. 409.

[11] On the occasion of the transit of Mercury, on the 4th of May, 1832, Mädler and William Beer (*Beiträge zur phys. Kenntniss der himmlischen Körper*, 1841, p. 145) found the diameter of Mercury 2,332 miles; but in the edition of the *Astronomie* of 1849, Mädler has given the preference to Bessel's result.

The *mass* of Mercury was determined by Lagrange upon very bold assumptions as to the reciprocity of the relations of distances and densities. A means of improving this element was first afforded by *Encke's Comet* of short period of revolution. The mass of this planet was fixed by Encke at $\frac{1}{4865751}$ of the Sun's mass, or about $\frac{1}{13 \cdot 7}$ of the Earth's. Laplace[12] gave the mass of Mercury as $\frac{1}{2025810}$ according to Lagrange; but the true mass is only $\frac{5}{12}$ of that assigned by Lagrange. By this correction also, the previous hypothesis of the rapid increase of density in the planets in proportion as they were nearer to the Sun, was disproved. When, with Hansen, the material contents of Mercury are assumed to be $\frac{6}{100}$ those of the Earth, the resulting *density* of Mercury is 1·22. "These determinations," adds my friend, the author of them, "are to be considered only as first attempts, which, nevertheless, come much nearer the truth than the numbers assumed by

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[12] Laplace, *Exposition du Syst. du Monde*, 1824, p. 209. The celebrated author admits, however, that in the determination of the mass of Mercury, he founded his opinion upon the "hypothèse très précaire qui suppose les densités de Mercure et de la Terre réciproques à leur moyenne distance du Soleil." "The very precarious hypothesis which supposes the densities of Mercury and the Earth reciprocal to their mean distance from the Sun." I have not considered it necessary to mention either the chain of mountains, 61,826 feet in height, which Schröter states that he saw upon the disc of Mercury and measured, and which Kaiser (*Sternenhimmel*, 1850, § 57) doubts the existence of; or the visibility of an atmosphere round Mercury during his transit over the Sun, asserted by Lemonnier and Messier (Delambre, *Hist. de l'Astronomie au dixhuitième siècle*, p. 222), or the temporary darkening of the surface of the planet. On the occasion of the transit which I observed in Peru on the 8th of November, 1802, I very closely examined the outline of the planet during the egress, but observed no indications of an envelope.

Laplace." Ten years ago the density of Mercury was taken as nearly three times greater than the density of the Earth—as 2·56 or 2·94, when the Earth = 1·00.

VENUS.

The mean distance of this planet from the Sun, expressed in fractional parts of the Earth's distance from the Sun, *i. e.* 60 million geographical miles, is 0·7233317. The period of its sidereal, or true revolution, is 224 days, 16h. 49m. 7s. No principal planet comes so near the Earth as Venus. She can approach the Earth to within a distance of 21 million miles; but can also recede from it to a distance of 144 million miles. This is the reason of the great variability of her apparent diameter, which by no means alone determines the degree of brilliancy.[13] The excentricity of the orbit of Venus

[13] "That point of the orbit of Venus in which she can appear to us with the brightest light, so that she may be seen at noon even with the naked eye, lies between the inferior conjunction and the greatest digression near the latter, and near the distance of 40° from the Sun, or from the place of the inferior conjunction. On the average, Venus appears with the finest light when distant 40° east or west from the Sun, in which case her apparent diameter (which in the inferior conjunction can increase to 66″) is only 40″, and the greatest breadth of her illuminated phase measures scarcely 10″. The degree of proximity to the Earth then gives the small luminous crescent such an intense light, that it throws shadows in the absence of the Sun."—Littrow, *Theoretische Astronomie*, 1834, Th. ii. p. 68. Whether Copernicus *predicted* the necessity of a future discovery of the phases of Venus, as is asserted in Smith's *Optics*, sec. 1050, and repeatedly in many other works, has recently become altogether doubtful, from Professor de Morgan's strict examination of the work *de Revolutionibus*, as it has come down to us.—See the letter

expressed, as in all cases, in fractional parts of half the major axes, is only 0·00686182. The diameter of this planet is 6,776 geographical miles; the mass $\frac{1}{401839}$, the material contents 0·957, and the density 0·94 in comparison to the Earth.

Of the transits of the two *inferior* planets first announced by Kepler after the appearance of his Rudolphine tables, that of Venus is of most importance for the theory of the whole planetary system, on account of the determination of the *Sun's parallax*, and the distance of the Earth from the Sun deduced from the latter. According to Encke's thorough investigation of the transit of Venus in 1769, the Sun's parallax is 8″·57116. (*Berliner Jahrbuch* for 1852, p. 323.) A new examination of the Sun's parallax has been undertaken since 1849, by command of the Government of the United States, at the suggestion of Professor Gerling of Marburg. The parallax is to be obtained by means of observations of Venus near the eastern and western stationary points, as well as by micrometer measurements of the differences in the right ascension and declination of well-determined fixed stars in *very different latitudes and longitudes*. (Schum. *Astr. Nachr.* No. 599, p. 363, and No. 613, p. 193.) The astronomical expedition, under the command of the learned Lieutenant Gilliss, has proceeded to Santiago in Chili.

The *rotation* of Venus was long subject to great doubt. Dominique Cassini, 1669, and Jacques Cassini, 1732, found it 23h. 20m., while Bianchini[14] of Rome, 1726, assumed the

from Adams to the Rev. R. Main, on the 7th of September, 1846, in the *Report of the Royal Astronomical Society*, vol. vii. No. 9, p. 142. (Compare also *Cosmos*, vol. ii. p. 708.)

[14] Delambre, *Hist. de l'Astron. au dixhuitième siècle*, pp. 256–258. The result obtained by Bianchini, was supported by Hussey and Flaugergues; Hansen also, whose

slow rotation of 24⅓ days. More accurate observations by De Vico, from 1840 to 1842, afford, by means of a great number of spots upon Venus, as the mean value of her period of rotation, 23h. 21′ 21″·93.

These spots are not very distinct, and are mostly variable; they seldom appear at the boundary of the separation between light and shadow in the crescent-shaped phase of the planet, and both the Herschels, father and son, are, consequently, of opinion that they do not belong to the solid surface of the planet, but more probably to an atmosphere.[16] The changeable form of the horns of the crescent, especially the southern, has been taken advantage of by La Hire, Schröter, and Mädler, partly for the estimation of the height of mountains, partly and more especially for the determination of the *rotation*. The phenomena of this changeability are of such a nature that they do not require for their explanation the assumption of the existence of mountain-peaks, twenty geographical miles in height (121,520 feet), as Schröter of Lilienthal stated, but merely elevations like those which our planet presents in

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authority is justly so great, considered it to be the more probable until 1836. (Schumacher's *Jahrbuch* for 1837, p. 90.)

[16] Arago on the remarkable observation at Lilienthal on the 12th of August, 1700, in the *Annuaire* for 1842, p. 539. ("Ce qui favorise aussi la probabilité de l'existence d'une atmosphère qui enveloppe Vénus, c'est le résultat optique obtenu par l'emploi d'une lunette prismatique. L'intensité de la lumière de l'intérieur du croissant est sensiblement plus faible que celle des points situés dans la partie circulaire du disque de la planète." Arago, *Manuscripts* of 1847.—"That circumstance which also favours the probability of the existence of an atmosphere surrounding Venus, is the optical result obtained by employing a prismatic telescope. The intensity of the light of the interior of the crescent is sensibly weaker than that of the points situated in the circular part of the planet's disc."

both continents.[16] With the little that we know with certainty of the appearance of the surfaces of the planets near the Sun, Mercury and Venus, and their physical constitution, the phenomenon of an ash-coloured light, sometimes observed in the dark parts, and mentioned by Christian Mayer, William Herschel,[17] and Harding, also remains exceedingly mysterious. It is not probable that at so great a distance the reflected light of the Earth should produce an ash-coloured illumination upon Venus as upon our Moon. Hitherto there has been no flattening observed in the discs of the two inferior planets, Mercury and Venus.

THE EARTH.

The mean distance of the Earth from the Sun is 12,032 times greater than the diameter of the Earth; therefore, 82,728,000 geographical miles, uncertain as to about 360,000 miles ($\frac{1}{230}$). The period of the sidereal revolution of the Earth round the Sun is 365d. 6h. 9′ 10″·7496. The excentricity of the Earth's orbit amounts to 0·01679226; its mass is $\frac{1}{359551}$; its density in relation to water, 5·44. Bessel's investigation of ten measurements of degrees, gave for the flattening of the Earth, $\frac{1}{299 \cdot 153}$. The length of a geographical mile, sixty of which are contained in one equatorial degree, 951,807 toises, and the equatorial and polar diameters, 6875·6 and 6852·4 geographical miles. (*Cosmos*, vol. i. p. 157, note.)

[16] Wilhelm Beer and Mädler, *Beiträge zur Physischen Kenntniss der Himmlischen Körper*, p. 148. The so-called moon of Venus, which Fontana, Dominique Cassini, and Short declared that they had seen, for which Lambert calculated tables, and which was said to have been seen in the centre of the Sun's disc, full three hours after the egress of Venus, belongs to the astronomical myths of an uncritical age.

[17] *Philos. Transact.* 1795, vol. lxxxvi. p. 214.

We restrict ourselves here to numerical data referring to the Earth's figure and motions: all that refers to its physical constitution is deferred until the concluding terrestrial portion of the Cosmos.

The Moon of the Earth.

The mean distance of the Moon from the Earth is 207,200 geographical miles; the period of sidereal revolution is 27d. 7h. 43′ 11″·5; the excentricity of her orbit, 0·0548442; her diameter is 1816 geographical miles, nearly one-fourth of the Earth's diameter; her material contents $\frac{1}{54}$ those of the Earth; the mass of the Moon is, according to Lindeman, $\frac{1}{87\cdot73}$ (according to Peters and Schidloffsky, $\frac{1}{81}$) of the mass of the Earth, her density 0·619, therefore nearly three-fifths of the density of the Earth. The Moon has no perceptible flattening, but an extremely slight prolongation on the side towards the Earth, estimated theoretically. The rotation of the Moon upon its axis is completed exactly in the same time in which it revolves round the Earth, and this is probably the case with all other secondary planets.

The sunlight reflected from the Moon is in all zones more feeble than the sunlight which is reflected by a white cloud in the daytime. When in determining geographical longitudes it is often necessary to take the distance of the Moon from the Sun, it is not unfrequently difficult to distinguish the Moon between the more intensely luminous masses of cloud. Upon mountain-heights, which lie between 12,791 and 17,057 feet above the level of the sea, and where in the clear mountain air only feathery cirri are to be seen in the sky, I found the detection of the Moon's disc was much more easy, because the cirrus reflects less sunlight on account of its loose texture, and the moonlight is less weakened by its passage through the rarer strata of air. The relative degree of in-

tensity of the Sun's light to that of the full Moon deserves a new investigation, as Bouguer's universally received determination $\frac{1}{300000}$, differs so widely from the certainly less probable one of Wollaston, $\frac{1}{800000}$.[18]

The yellow moonlight appears white by day, because the blue strata of air through which we see it present the complementary colour to yellow.[19] According to the numerous observations which Arago made with his polariscope, the moonlight contains *polarized* light; it is most perceptible during the first quarter and in the grey spots of the Moon's surface; for example, in the great, dark, sometimes rather greenish walled plains, the so-called *Mare Crisium*. Such walled plains are generally intersected by mountain veins, in whose polyhedric figure the surfaces are inclined at that angle which is necessary for the polarization of the reflected sunlight. The dark tint of the surrounding space appears in addition to make the phenomenon still more obvious. With regard to the luminous central mountain of the group *Aristarchus*, upon which it has been frequently erroneously supposed that volcanic action has been seen, it did not present any greater polarization of light than other parts of the Moon. In the full Moon no admixture of polarized light was observable; but during a total eclipse of the Moon (31st of

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[18] *Cosmos*, vol. iii. p. 126 and note.

[19] "La lumière de la Lune est jaune, tandis que celle de Vénus est blanche. Pendant le jour la Lune parait blanche, parcequ'à la lumière du disque lunaire se mêle la lumière bleue de cette partie de l'atmosphère que la lumière jaune de la Lune traverse."—(Arago, in *Handschr.* of 1847), "The light of the Moon is yellow, while that of Venus is white. The Moon appears white during the day, because the blue light of that part of the atmosphere which the yellow light of the Moon traverses, mixes with the light of the lunar disc." The most refrangible rays of the spectrum, from blue to violet, unite with the less refrangible, from red to green, to form white. (*Cosmos*, vol. iii. p. 282, note 19.)

May, 1848), Arago detected indubitable signs of polarization in the reddened disc of the Moon, the latter being a phenomenon of which we shall speak further on. (*Comptes rendus*, tom. xviii. p. 119.)

That the moonlight is *capable of producing heat* is a discovery which belongs, like so many others of my celebrated friend Melloni, to the most important and surprising of our century. After many fruitless attempts, from those of La Hire to the sagacious Forbes,[20] Melloni was fortunate enough to observe by means of a lens (*lentille à échellons*) of three feet in diameter, which was destined for the meteorological station on Vesuvius, the most satisfactory indications of an elevation of temperature during different changes of the Moon. Mosotti-Lavagna and Belli, professors of the Universities of Pisa and Pavia, were witnesses of these experiments, which gave results differing in proportion to the age and altitude of the Moon. It had not at that time (Summer, 1848) been determined what the elevation of temperature produced by Melloni's thermoscope, expressed in fractional parts of the centigrade thermometer, amounted to.[21]

[20] Forbes, *On the Refraction and Polarization of Heat*, in the *Transact. of the Royal Society of Edinburgh*, vol. xiii. 1836, p. 131.

[21] *Lettre de M. Melloni à M. Arago sur la puissance calorifique de la lumière de la Lune*, in the *Comptes rendus*, tom. xxii. 1846, pp. 541–544. Compare also on account of the historical data the *Jahresbericht der Physicalischen Gessellschaft zu Berlin*, Bd. ii. p. 272. It had always appeared sufficiently remarkable to me that from the earliest times, when heat was determined only by the sense of feeling, the Moon had first excited the idea that light and heat might be separated. Among the Indians the Moon was called, in Sanscrit, the King of the stars *of cold* (*'sîtala, hima*), also the *cold-radiating* (*himân'su*), while the Sun was called *a creator of heat* (*niddâghakara*). The spots upon the Moon, in which

The *ash-grey* light with which a part of the Moon's disc shines when, some days before or after the new Moon, she presents only a narrow crescent, illuminated by the Sun, is *earth-light* in the Moon, "the reflection of a reflection." The less the Moon appears illuminated for the Earth, so much the more is the Earth luminous for the Moon. But our planet shines upon the Moon with an intensity 13½ times greater than the Moon upon the Earth; and this light is sufficiently bright to become again perceptible to us by a *second* reflection. By means of the telescope, mountain-peaks are distinguished in the *ash-grey* light of the larger spots and isolated brightly-shining points; even when the disc is already more than half illuminated.[a] These phenomena become particularly striking between the tropics and upon the high mountain-plains of Quito and Mexico. Since the time of Lambert and Schröter the opinion has become prevalent that the extremely variable intensity of the ash-grey

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Western nations supposed they discerned a *face*, represent, according to the Indian notion, a roebuck or a hare; thence the Sanscrit name of the Moon (*mrigadhara*), *roebuck-bearer*, or (*'sa'sabhrit*), *hare-bearer*. (Schütz, *Five Hymns of the Bhatti-Kávya*, 1837, p. 19–23.) Among the Greeks it was complained "that the sunlight reflected from the Moon should lose all heat, so that only feeble remains of it were transmitted by her." (Plutarch, in the dialogue "*De facia quæ in orbe Lunæ apparet*, *Moralia*, ed. Wyttenbach, tom. iv. Oxon. 1797, p. 793). In Macrobius (*Comm.* in *Somnium Scip.* i. 19, ed. Lud. Janus, 1848, p. 105) it is said: "Luna speculi instar lumen quo illustratur.......rursus emittit, nullum tamen ad nos preferentem sensum caloris: quia lucis radius, cum ad nos de origine sua, id est de Sole, pervenit, naturam secum ignis de quo nascitur devehit; cum vero in Lunæ corpus infunditur et inde resplendet, solam refundit claritatem, non calorem." The same in Macrobius, *Saturnal.* lib. vii. cap. 16, ed. Bipont. tom. ii. p. 277.

[a] Mädler, *Astron.* § 112.

light of the Moon depends upon the greater or less degree of reflection of the sunlight which falls upon the Earth, according as it is reflected from continuous continental masses, full of sandy deserts, grassy steppes, tropical forests, and barren rocky ground, or from large ocean surfaces. Lambert made the remarkable observation (14th of February, 1774) of a change of the ash-coloured moonlight into an olive green colour, bordering upon yellow. "The Moon, which then stood vertically over the Atlantic Ocean, received upon its night side the green terrestrial light, which is reflected towards her when the sky is clear by the forest districts of South America." [23]

The meteorological condition of our atmosphere modifies the intensity of the earth-light, which has to traverse the double course from the Earth to the Moon, and from thence to our eye. "Thus when we have better photometric instruments at our command we may be able," as Arago remarks,[24]

[23] See Lambert, *Sur la Lumière Cendrée de la Lune* in the *Mém. de l'Acad. de Berlin, année* 1773, p. 46: "La Terre, vue des planètes, pourra paroître d'une lumière verdâtre, à peu près comme Mars nous paroît d'une couleur rougeâtre." "The Earth, seen from the planets, may appear of a green colour, much the same as Mars affords to us of a reddish colour." We will not, however, on that account, conjecture with this acute man, that the planet Mars may be covered with a red vegetation such as the rose-red bushes of Bougainvillaea. (Humboldt, *Views of Nature*, p. 334.) "When in central Europe the Moon, *shortly before the new Moon*, stands in the eastern heavens during the morning hour, she receives the earth-light principally from the large plateau surfaces of Asia and Africa. But *if after the new Moon* it stands during the evening in the west, it can only receive the reflection in less quantities from the narrower American continent, and principally from the wide ocean." Wilhelm Beer and Mädler, *der Mond nach seinen Cosmischen Verhältnissen*, § 106, p. 152.

[24] *Séance de l'Académie des Sciences, le* 5 *Août*, 1833,

"to read in the Moon the history of the *mean condition* of the diaphanity of our atmosphere." The first correct explanation of the nature of the ash-coloured light of the Moon is ascribed by Kepler (*ad Vitellionem Paralipomena, quibus, Astronomiæ pars optica traditur*, 1604, p. 254) to his highly venerated teacher Mästlin, who had made it known in a thesis publicly defended at Tübingen in 1596. Galileo spoke (*Sidereus Nuncius*, p. 26) of the reflected terrestrial light, as a phenomenon which he had discovered several years

"M. Arago signale la comparaison de l'intensité lumineuse de la portion de la Lune que les rayons solaires éclairent directement, avec celle de la partie du même astre qui reçoit seulement les rayons réfléchis par la Terre. Il croit d'après les expériences qu'il a déjà tentées à cet égard, qu'on pourra, avec des instrumens perfectionnés, saisir dans la *lumière cendrée* les différences de l'éclat plus ou moins nuageux de l'atmosphère de notre globe. Il n'est donc pas impossible, malgré tout ce qu'un pareil résultat exciterait de surprise au premier coup d'œil, qu'un jour les météorologistes aillent puiser dans l'aspect de la Lune des notions précieuses sur *l'état moyen* de diaphanité de l'atmosphère terrestre, dans les hemisphères qui successivement concourrent à la production de la lumière cendrée."—"M. Arago pointed out the comparison between the luminous intensity of that portion of the Moon which is illuminated directly by the solar rays, and that portion of the same body which receives only the rays reflected by the Earth. After the experiments which he has already made in reference to this subject, he is of opinion that with improved instruments it will be possible to detect in the *ashy light* indications of the differences in brightness, more or less cloudy, of the atmosphere of our globe. It is not therefore impossible, notwithstanding the surprise which such a result may excite on the first view, that one day meteorologists will derive valuable ideas as to the *mean state* of the diaphanity of our atmosphere in the hemispheres which successively contribute to the production of the ashy light."

previously; but a century before Kepler and Galileo, the explanation of terrestrial light visible to us in the Moon, had not escaped the all-embracing genius of Leonardo da Vinci. His long-forgotten manuscripts furnished a proof of this.[25]

In the total eclipse of the Moon, the disc very rarely disappears entirely; it did so, according to Kepler's earliest observation,[26] on the 9th of December, 1601, and more recently, on the 10th of June, 1816; in the latter instance so as not to be visible from London, even by the aid of telescopes. The cause of this rare and extraordinary phenomenon must be a peculiar and not sufficiently investigated diaphanic condition of individual strata of our atmosphere. Hevelius states distinctly that during a total eclipse, on the 25th of April, 1642. the sky was covered with brilliant stars, the atmosphere perfectly clear and yet with the different magnifying powers which he employed, not a vestige of the Moon could be seen. In other cases, likewise very rare, only separate parts of the Moon are feebly visible. During a total eclipse, the disc generally appears red; and, indeed, in all degrees of intensity of colour, even passing, when the Moon is far distant from the Earth, into a fiery and glowing red. While lying at anchor off the island of Baru, not far from Carthagena de Indias, half a century ago (29th of March, 1801), I observed a total eclipse, and was extremely struck with the greater luminous intensity of the Moon's disc under a tropical sky than in my native north.[27] The whole

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[25] Venturi, *Essai sur les Ouvrages de Leonard de Vinci* 1797, p. 11.

[26] Kepler, *Paralip. vel Astronomiæ pars opticæ*, 16[illegible]4, p. 297.

[27] "On conçoit que la vivacité de la lumière rouge ne dépend par uniquement de l'état de l'atmosphère, qui réfracte, plus ou moins affaiblis, les rayons solaires, en les enfléchissant dans le cône d'ombre, mais qu'elle est modifiée surtout par la

phenomenon is known to be a consequence of refraction, since, as Kepler very correctly expresses himself (*Paralip. Astron. pars Optica*, p. 893), the Sun's rays are inflected[28]

transparence variable de la partie de l'atmosphère à travers laquelle nous apercevons la Lune éclipsée. Sous les tropiques, une grande sérénité du ciel, une dissémination uniforme des vapeurs diminuent l'extinction de la lumière que le disque lunaire nous renvoie."—Humboldt, *Voyage aux Régions Equinoxiales*, tom. iii. p. 544; and *Recueil d'Observ. Astronomiques*, vol. ii. p. 145. "It may easily be understood that the intensity of the red light does not depend solely upon the state of the atmosphere which refracts more or less feebly the solar rays by inflecting them into the shadow cone, but that it is especially modified by the variable transparency of that part of the atmosphere across which we perceive the eclipsed Moon. Under the tropics a great serenity of sky, an uniform dissemination of vapours, diminish the extinction of the light which the lunar disc sends towards us." Arago observes: "Les rayons solaires arrivent à notre satellite par l'effet d'une réfraction et à la suite d'une absorption dans les couches les plus bases de l'atmosphère terrestre; pourraient-ils avoir une autre teinte que le rouge?"—*Annuaire* for 1842, p. 528. "The solar rays reach our planet by the effect of a refraction, and subsequently to an absorption (partial) in the lower strata of the Earth's atmosphere. How can they have any other colours than red?"

[28] Babinet declares the reddening to be a consequence of *diffraction*, in a memoir as to the different share of the white, blue, and red lights which are produced by the inflection; see his Reflections upon the Total Eclipse of the Moon on the 19th of March, 1848, in Moigno's *Répertoire d'Optique Moderne*, 1850, tom. iv. p. 1656. "La lumière diffractée qui pénètre dans l'ombre de la Terre, prédomine toujours et même a été seule sensible. Elle est d'autant plus rouge ou orangée qu'elle se trouve plus près du centre de l'ombre géométrique; car se sont les rayons les moins réfrangibles qui se propagent le plus abondamment par diffraction, à mesure qu'on s'éloigne de la propagation en ligne droite."—"The diffracted light which penetrates into the Earth's

by their passage through the atmosphere, and thrown into the shadow cone. The reddened or glowing disc is moreover never uniformly coloured. Some places always appear darker, and are at the same time continually changing colour. The Greeks had formed a peculiar and curious theory with respect to the different colours which the eclipsed Moon was said to present according to the hour at which the eclipse took place.[29]

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shadow, always predominated, and was indeed alone sensible. It was the more red or orange, in proportion as it was nearer to the geometrical centre of the shadow; for those rays which are least refrangible are those which are propagated most abundantly by diffraction, in proportion as they differ from a rectilinear course." The phenomena of diffraction take place as well in a vacuum, according to the acute investigations of Magnus (on the occasion of a discussion between Airy and Faraday). Compare, in reference to the explanations by diffraction in general, Arago in the *Annuaire* for 1846, p. 452–455.

[29] Plutarch (*De Facie in orbe Lunæ*), *Moral.* ed. Wytten. tom. iv. p. 780–783: "The fiery, charcoal-like glimmering (ἀνθρακοειδής) colour of the eclipsed Moon (about the midnight hour) is, as the mathematicians affirm, owing to the change from black into red and bluish, and is by no means to be considered as a character peculiar to the earthy surface of the planet." Also Dio Cassius (lx. 26, ed. Sturz, p. iii. p. 779), who occupied himself especially with eclipses of the Moon, and the remarkable edicts of the Emperor Claudius, which *predicted* the *dimensions* of the eclipsed portion, directs attention to the very different colours which the Moon assumed during the conjunction. He says, (lxv. 11, tom. iv. p. 185, Sturtz,) "Great was the excitement in the camp of Vitellus, in consequence of the eclipse which took place that night. The mind was filled with melancholy apprehensions, not so much at the eclipse itself, although that might appear to predict misfortune to an unquiet mind, but much more from the circumstance that the Moon displayed blood-red, black, and other gloomy colours."

During the long dispute as to the probability or improbability of an atmospheric envelope round the Moon, accurate occultation observations have proved that no refraction takes place on the surface of the Moon, and that consequently the assumption made by Schröter[30] of the existence of a lunar atmosphere and a *lunar twilight* are disproved. "The comparison of the two values of the Moon's diameter which may be respectively deduced from direct measurement, or from the length of time that it remains before a fixed star during the occultation, teaches us that the light of a fixed star is *not perceptibly* deflected from its rectilinear course at that moment in which it touches the Moon's edge. If a refraction took place at the edge of the Moon, the second determination of her diameter must give a value smaller by twice the amount of the refraction than the former; but on the contrary, both determinations correspond so closely in repeated determinations, that no appreciable difference has ever been detected."[31] The ingress of stars, which may be particularly well observed at the dark edge, takes place suddenly, and

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[30] Schröter, *Selenotopographischte Fragmente*, th. i. 1791, p. 668; th. ii. 1802, p. 52.

[31] Bessel, *Ueber eine angenommene Atmosphäre des Mondes* in Schumacher's *Astron. Nachr.* No. 263. pp. 416–420. Compare also Beer and Mädler, *der Monde*, § 83 and 107, pp. 133 and 153; also Arago, in the *Annuaire* for 1846, pp. 346–353. The frequently mentioned proof of the existence of *an atmosphere round the Moon*, derived from the greater or less perceptibility of small superficial configurations and "the *Moon-clouds* moving round in the valleys," is the most untenable of all, on account of the continually-varying condition (darkening and brightening) of the upper strata of our own atmosphere. Considerations as to the form of one of the *Moon's horns* on the occasion of the solar-eclipse on the 5th of September, 1793, induced William Herschel to decide *against* the assumption of a lunar atmosphere. (*Philos. Transact.* vol. lxxxiv. p. 167.)

without gradual diminution of the star's brilliancy; just so the egress or reappearance of the star. In the case of the few exceptions which have been described, the cause may have consisted in accidental changes of our atmosphere.

If, however, the Earth's Moon is destitute of a gaseous envelope, the stars must appear then, in the absence of all diffuse light, to rise upon a black sky;[32] no air-wave can there convey sound, music, or language. To our imagination, so apt presumptuously to stray into the unfathomable, the Moon is a voiceless wilderness.

The phenomenon of apparent adherence on and within the Moon's edge,[33] sometimes observed in the occultation of stars, can scarcely be considered as a consequence of *irradiation*, which, in the narrow crescent of the Moon, on account of the very different intensity of the light in the ash-coloured part of the Moon, and in that which is immediately illuminated by the Sun, certainly makes the latter appear as if surrounding the former. Arago saw during a total eclipse of the Moon, a star distinctly adhere to the slightly luminous disc of the Moon during the conjunction. It still continues to be a subject of discussion between Arago and Plateau whether the phenomenon here mentioned depends upon deceptive perception and physiological causes,[34] or upon the aberration of

[32] Mädler, in Schumacher's *Jahrbuch für* 1840, p. 188.

[33] Sir John Herschel (*Outlines*, p. 247) directs attention to the ingress of such *double stars* as cannot be seen separately by the telescope, on account of the too great proximity of the individual stars of which they consist.

[34] Plateau, *Sur l'Irradiation*, in the *Mém. de l'Acad. Royale des Sciences et Belles-Lettres de Bruxelles*, tom. xi. p. 142, and the supplementary volume of Poggendorff's *Annalen*, 1842, pp. 79–128, 193–232, and 405 and 443. "The probable cause of the irradiation is an irritation produced by the light upon the retina, and spreads a little beyond the outline of the image."

sphericity and refrangibility of the eye.[35] Those cases in which it has been asserted that a disappearance and reappearance, and then a repeated disappearance, have been observed during an occultation, may probably indicate the ingress to have taken place at a part of the Moon's edge which happened to be deformed by mountain declivities and deep chasms.

The great differences in the reflected light from particular regions of the illuminated disc of the Moon, and especially the absence of any sharp boundary between the inner edge of the illuminated and ash-coloured parts in the Moon's phases, led to the formation of several very rational theories as to the inequalities of the surface of our satellite, even at a very remote period. Plutarch says distinctly, in the small but very remarkable work *On the Face in the Moon*, that we may suppose the *spots* to be partly deep chasms and valleys, partly mountain peaks, "which cast long shadows, like

[35] Arago, in the *Comptes Rendus*, tom. viii. 1839, pp. 713 and 883. "Les phénomènes d'irradiation signalés par M. Plateau sont regardés par M. Arago comme les effets des aberrations de refrangibilité et de sphéricité de l'œil, combinés avec l'indistinction de la vision, conséquence des circonstances dans lesquelles les observateurs se sont placés. Des mesures exactes prises sur des disques noirs à fond blanc et des disques blancs à fond noir, qui étoient placés au Palais du Luxembourg, visibles à l'observatoire, n'ont pas indiqué les effets de l'irradiation." "The phenomena of irradiation pointed out by M. Plateau are regarded by M. Arago as the effects of the aberration of sphericity and refrangibility of the eye, combined with the indistinctness of vision consequent upon the circumstances in which the observers are placed. The exact measurement taken of the black discs upon a white ground, and the white discs upon a black ground which were placed upon the palace of Luxembourg, and visible at the Observatory, did not present any phenomena of irradiation."

Mount Athos, whose shadow reaches Lemnos."[36] The *spots* cover about two-fifths of the whole disc. In a clear atmosphere, and under favourable circumstances in the position of the Moon, some of the spots are visible to the naked eye; the ridge of the Apennines, the dark walled plain *Grimaldus*, the detached *Mare Crisium*, and *Tycho*,[37] crowded round with numerous mountain ridges and craters. It has been affirmed, not without probability, that it was especially the aspect of the *Apennine chain*, which induced the Greeks to consider the spots on the Moon to be mountains, and at the same time to associate with them the shadow of Mount Athos, which in the solstices reached the Brazen Cow upon Lemnos. Another very fantastic opinion was that of Agesinax, disputed by Plutarch, according to which the Moon's disc was supposed, like a mirror, to present to us again, catoptrically, the configuration and outline of our continent, and the *outer* sea (the Atlantic). A very similar opinion appears to have been preserved to this time as a popular belief among the people in Asia Minor.[38]

[36] Plutarch, *Moral.* ed. Wytten. tom. iv. pp. 786–789. The shadow of Athos, which was seen by the traveller Pierre Belon (*Observations de singularités trouvées en Grèce, Asie, etc.* 1554, liv. i. chap. 25), reached the brazen cow in the market-town Myrine in Lemnos.

[37] Proofs of the visibility of these four objects, see in Beer and Mädler, *der Mond*, pp. 241, 338, 191, and 290. It is scarcely necessary to mention that all which refers to the topography of the Moon's surface is derived from the excellent work of my two friends, of whom the second, William Beer, was taken from us but too early. The beautiful *Uebersichtsblatt*, which Mädler published in 1837, three years after the large map of the Moon, consisting of three sheets, is to be recommended for the purpose of more easily becoming acquainted with the bearings.

[38] Plut. *De facie in orbe Lunæ*, pp. 726–729, Wytten. This

By the careful application of large telescopes, it has gradually become possible to construct a topographical chart of the Moon, based upon actual observations; and since, in the opposition, the entire half-side of the Earth's satellite presents itself at the same moment to our investigation, we know more of the general and merely formal connection of the mountain groups in the Moon, than of the orography of a whole terrestrial hemisphere containing the interiors of Africa and Asia. Generally the *darker* parts of the disc are

passage is, at the same time, not without interest for ancient geography.—See Humboldt, *Examen critique de l'Hist. de la Géogr.* tom. i. p. 145. With regard to other views of the ancients, see Anaxagoras and Democritus, in Plut. *de plac. Philos.* ii. 25; Parmenides, in *Stob.* pp. 419, 453, 516, and 563, ed. Heeren; Schneider, *Eclogæ physicæ*, vol. i. pp. 433–443. According to a very remarkable passage in Plutarch's *Life of Nicias*, cap. 42, Anaxagoras himself, who calls "the mountainous Moon another Earth," had made a drawing of the Moon's disc. (Compare also Origines, *Philosophumena*, cap. 8, ed. Mülleri, 1851, p. 14.) I was once very much astonished to hear a very well-educated Persian, from Ispahan, who certainly had never read a Greek book, mention, when I showed him the Moon's spots in a large telescope in Paris, the hypothesis of Agesinax, (alluded to in the text,) as to the reflection, as a widely-diffused popular belief in his country. "What we see there in the Moon," said the Persian, "is ourselves; it is the map of our Earth." One of the interlocutors in Plutarch's *Moon-dialogue*, would not have expressed himself otherwise. If it can be supposed that men are inhabitants of the Moon, destitute of water and air, the Earth, with its spots, would also present to them such a *map* upon a *nearly black sky by day*, with a surface fourteen times greater than that which the full Moon presents to us, and always in the same position. But the constantly varying clouds and obscurities of our atmosphere, would confuse the outlines of the continents.—Compare Mädler's *Astron.* p. 169, and Sir John Herschel, *Outlines*, § 436.

the lower and more level; the *brighter* parts, reflecting much Sun-light, are the more elevated and mountainous Kepler's old description of the two as *sea* and *land*, has long been given up; and the accuracy of the explanation, and the opposition, was already doubted by Hevel, notwithstanding the similar nomenclature introduced by him. The circumstance principally brought forward as disproving the presence of surfaces of water on the Moon, was that in the so-called *seas of the Moon*, the smallest parts showed themselves, upon closer examination and very different illumination, to be completely *uneven*, polyhedric, and consequently giving much *polarized* light. Arago has pointed out, in opposition to the arguments which have been derived from the irregularities, that some of these surfaces may, notwithstanding the irregularities, be covered with water, and belong to the bottoms of seas of no great depth, since the uneven *craggy* bottom of the ocean of our planet is distinctly seen when viewed from a great height, on account of the preponderance of the light issuing from below its surface, over the intensity of that which is reflected from it. (*Annuaire du Bureau des Longitudes pour* 1836, pp. 339–343.) In the work of my friend, which will shortly appear, on astronomy and photometry, the probable absence of water upon our satellite will be deduced from other optical grounds, which cannot be developed in this place. Among the low *plains*, the *largest* surfaces are situated in the northern and eastern parts. The indistinctly bounded *Oceanus Procellarum*, has the greatest extension of all these, being 360,000 geographical miles. Connected with the *Mare Imbrium* (64,000 square miles), the *Mare Nubium*, and to some extent with the *Mare Humorum*, and surrounding insular mountain districts (the *Riphæi*, *Kepler*, *Copernicus*, and the *Carpathians*), this *eastern* part of the Moon's disc presents the most decided contrast to the luminous *south-western* district, in which mountain is crowded

upon mountain:[39] In the north-west region, two basins present themselves as being more shut in and isolated, the *Mare Crisium* (12,000 square miles), and the *Mare Tranquillitatis* (23,200 square miles).

The colour of these so-called *seas* is not in all cases grey. The *Mare Crisium* is grey mixed with dark-green, the *Mare Serenitatis* and *Mare Humorum* are likewise green. Near the *Hercynian* mountains, on the contrary, the isolated circumvallation *Lichtenberg* presents a pale reddish colour, the same as *Palus Somnii*. Circular surfaces, without central mountains, have for the most part a dark steel-grey colour, bordering upon bluish. The causes of this great diversity in the tints of the rocky surface, or other porous materials which cover it, are extremely mysterious. While to the northwards of the Alpine mountains, a large enclosed plain, *Plato* (called by Hevel, *Lacus niger major*), and still more *Grimaldus* in the equatorial region, and *Endymion* on the north-west edge, are the three darkest spots upon the whole Moon's disc; *Aristarchus*, with its sometimes almost star-like shining points, is the brightest and most brilliant. All these alternations of light and shade affect an iodized plate, and may be represented in *Daguerreotype* by means of powerful magnifiers, with wonderful truthfulness. I myself possess such a *moonlight picture* of 2 inches diameter, in which the so-called *seas* and ring-formed mountains are distinctly perceptible; it was executed by an excellent artist, Mr. Whipple of Boston.

If the circular form is striking in some of the *seas* (*Crisium*, *Serenitatis*, and *Humorum*), it is still more frequently, indeed almost universally, repeated in the mountainous part of the disc; especially in the configuration of the enormous mountain-masses which occupy the southern hemisphere from the pole to near the equator, where the mass runs out in a point.

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[39] Beer and Mädler, p. 273.

Many of the annular elevations and inclosed plains (according to Lohrmann the largest are more than 4,000 square miles in extent) form connected *series*, and indeed in the *direction* of the *meridian*, between 5° and 40° South Latitude.[40] The northern polar region contains comparatively few of these crowded *mountain circles*. In the western edge of the northern hemisphere, on the contrary, they form a connected group between 20° and 50° North Latitude. The North Pole itself is within a few degrees of the *Mare Frigoris*, and thus, like the whole level north-eastern space, including only a few isolated annular mountains (*Plato*, *Mairan*, *Aristarch*, *Copernicus*, and *Kepler*), presents a great contrast to the South Pole, entirely covered with mountains. Here lofty peaks shine during whole lunations in *eternal light*, in the strictest sense of the word; they are true *light islands*, which become perceptible, even with feeble magnifying powers.[41]

As exceptions to this type of circular and annular configurations, so universally predominant upon the Moon, are the actual mountain-chains which occur almost in the middle of the northern half of the Moon (*Apennines*, *Caucasus*, and *Alps*). They extend from south to north in a slight curve towards the west, through nearly 32° of latitude. Innumerable mountain-crests, and extraordinary sharp peaks, are here thronged together. Few annular mountains, or crater-like depressions, are intermingled (*Conon*, *Hadley*, *Calippus*), and the whole resembles more the configuration of our mountain-chains upon the Earth. The *lunar Alps*, which are inferior in height to the *lunar Caucasus and Apennines*, present a remarkable *broad transverse valley*, which intersects the chain from south-east to north-west. It is surrounded by mountain-peaks, which exceed in height that of Teneriffe.

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[40] Schumacher's *Jahrbuch* for 1841, p. 270.
[41] Mädler, *Astron.* p. 166.

The relative height of the elevations, in proportion to the diameters of the Moon and the Earth, gives the remarkable result, that since in the four times smaller satellite the highest peaks are only 3,836 feet lower than those of the Earth, the lunar mountains amount to $\frac{1}{454}$, the mountains on the Earth to $\frac{1}{1481}$ of the planetary diameters.[43] Among the 1,095 points of elevation already measured upon the Moon, I find 39 are higher than Mont Blanc (16,944 feet) and 6 higher than 19,000 feet. The measurements were effected either by light tangents (by determining the distance of the illuminated mountain-peak on the right side of the Moon from the boundary of the light), or by the length of the shadows. The former method was already made use of by Galileo, as is seen from his letter to the Father Grienberger upon the *Montuosità della Luna.*

According to Mädler's careful measurements by means of the length of the shadows, the culminating points of the Moon are in descending order at the south edge, very near the Pole, *Dörfel* and *Leibnitz*, 24,297 feet; the annular mountain *Newton*, where a part of the deep hollow is never lighted, neither by the Sun nor the Earth's disc, 23,830 feet; *Casatus*, eastward of *Newton*, 22,820 feet; *Calippus*, in the Caucasian chain, 20,396 feet; the *Appenines*, between 17,903 and 19,182 feet. It must be remarked here, that in the entire absence of a general *niveau-line* (the plane of equal distance from the centre of a cosmical body, as is presented

[43] The highest peak of the Himalayas, and (up to the present time!) of the whole Earth, *Kinchin-junga*, is, according to Waugh's recent measurement, 4,406 toises, or 28,178 English feet; the highest peak among the Moon's mountains is, according to Mädler, 3,800 toises (exactly 4 geographical miles). The diameter of the Moon is 1,816, that of the Earth 6,872 geographical miles: whence it follows for the Moon $\frac{1}{454}$, for the Earth $\frac{1}{1481}$.

on our planet by the level of the sea), the absolute heights are not to be compared strictly with each other, since the six numerical results here given, properly express only the differences between the peaks and the immediately surrounding plains or hollows.[43] It is, however, very remarkable that Galileo likewise assigned to the loftiest lunar mountains the height of about 4 geographical miles (24,297 feet) "*incirca miglia quatro*," and in accordance with the extent of his hypsometric knowledge, considered them higher than any of the mountains on the Earth.

An extremely remarkable and mysterious phenomenon which the surface of our satellite presents, and which is only optically connected with a reflection of light, and not hypsometrically with a difference of elevation, consists in the narrow streaks of light which disappear when the illuminating rays fall obliquely; but in the full Moon, quite in opposition to the Moon-spots, become most visible as systems of rays. They are not mountain veins, cast no shadow, and run with equal intensity of light from the plains to elevations of more than 12,780 feet. The most extensive of these ray-systems commences from *Tycho*, where more than a hundred streaks of light may be distinguished, mostly several miles broad. Similar systems which surround the *Aristarchus*, *Kepler*, *Copernicus*, and the *Carpathians*, are almost all in connection with each other. It is difficult to conjecture, by the aid of induction and analogy, what special transformations of the surface give rise to these luminous, ribbon-like rays, proceeding from certain annular mountains.

The frequently mentioned type of circular configuration, almost everywhere preponderating upon the Moon's disc, in

[43] For the six heights which exceed 19,182 feet, see Beer and Mädler, pp. 99, 125, 234, 242, 330, and 331.

the *walled plains* which frequently surround *central mountains;* in the large *annular mountains* and their craters (22 are counted close together in *Bayer*, and 33 in *Albategnius*). must have early induced a deep-thinker like Robert Hooke, to ascribe such a form to the *reaction of the interior* of the Moon *upon the exterior.* "The action of subterranean fire, and elastic eruptive vapours, and even to an *ebullition* in eruptive bubbles. Experiments with thickened boiling lime solutions appeared to him to confirm his opinion; and the circumvallations, with their central mountains, were at that time already compared with "the forms of Ætna, the peak of Teneriffe, Hecla, and the Mexican volcanos described by Gage."[44]

One of the circular plains of the Moon reminded Galileo, as he himself relates, of the configuration of countries entirely surrounded by mountains. I have discovered a passage[45] in which he compares these circular plains of the Moon with the great inclosed basin of Bohemia. Many of the plains are in fact not much smaller; for they have a

[44] Robert Hooke, *Micrographia*, 1667, Obs. lx. pp. 242-246. "These seem to me to have been the effects of some motions within the body of the Moon, analogous to our earthquakes, by the eruption of which, as it has thrown up a brim or ridge round about, higher than the ambient surface of the Moon, so has it left a hole or depression in the middle, proportionably lower." Hooke says of his experiment with boiling alabaster: that "presently ceasing to boyl, the whole surface will appear all over covered with small pits, exactly shaped like those of the Moon. The earthy part of the Moon has been undermined, or heaved up by eruptions of vapours, and thrown into the same kind of figured holes as the powder of alabaster. It is not improbable also, that there may be generated within the body of the Moon, divers such kind of internal fires and heats as may produce exhalations."

[45] *Cosmos*, vol. ii. p. 701, note

diameter of from 100 to 120 geographical miles.[46] On the contrary, the real *annular mountains* scarcely exceed 8 or 12 miles in diameter. *Conon* in the *Apennines* is 8; and a crater which belongs to the shining region of *Aristarchus*, is said to present a breadth of only 25,576 feet, exactly the half of the diameter of the crater of Rucu-Pichincha, in the table-land of Quito, measured trigonometrically by myself.

Since we have in this place adhered to comparisons with well-known terrestrial phenomena and relations of magnitude, it is necessary to remark that the greater part of the plains and annular mountains of the Moon, are to be considered in the first place as *craters of elevation*, without *continuous* phenomena of eruption in the sense of the hypothesis of Leopold von Buch. What, according to the European standard, we call great upon the Earth—the elevation crater of Rocca Monsina, Palma, Teneriffe, and Santorin—becomes insignificant when compared with Ptolemy, Hipparchus, and many others of the Moon. Palma has only 24,297 feet diameter; Santorin, according to Captain Graves, new measurement, 33,148 feet; Teneriffe, at the utmost, 53,298 feet: consequently, only only one-eighth or one-sixth of the two craters of elevation of the Moon just mentioned. The small crater of the Peak of Teneriffe and Vesuvius (from 319 to 426 feet in diameter) could scarcely be seen by the aid of telescopes. *The by far greater number* of the annular mountains have no central mountain; and where there is one, it is described as being dome-formed or level (*Hevelius*, *Macrobius*), not as an *erupted cone with an opening*.[47] The active volcanos,

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[46] Beer and Mädler, p. 126. Ptolemæus is 96 miles in diameter; Alphons and Hipparchus 76 miles.

[47] *Arzachel* and *Hercules* are supposed to be exceptions: the former to have a crater upon its summit, the second a

which are stated to have been seen in the right side of the Moon (May 4, 1783); the phenomena of light in *Plato* which Bianchini (August 16, 1725), and Short (April 22, 1751), observed, are here mentioned only as of historical interest; since the sources of deception have long been fathomed, and lie in the more powerful reflection of the terrestrial light which certain parts of the surface of our planet throw upon the ash-coloured night side of the Moon.[63]

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lateral crater. These points, important in a geognostic point of view, deserve fresh investigation with more perfect instruments. (Schröter, *Selenotopographische Fragmente*, Th. ii. tab. 44 and 68, fig. 23.) Hitherto no signs have ever been detected of lava streams collected in deep hollows. The *radiated lines* which issue from *Aristoteles* in three directions, are ranges of hills. (Beer and Mädler, p. 236.)

[63] *Op. cit.* p. 151. Arago, in the *Annuaire* for 1842, p. 526. (Compare also Immanuel Kant, *Schriften der Physischen Geographie*, 1839, pp. 393–402). According to recent and more complete investigations, the temporary changes said to have been observed upon the surface of the Moon (the formation of new central mountains and craters in the *Mare Crisium*, *Hevelius*, and *Cleomedes*), are illusions of a similar nature to the supposed volcanic cruptions perceptible to us upon the Moon. (See Schröter, *Selenotopographische Fragmente*, Th. i. pp. 412–523; Th. ii. pp. 268–272.) The question, what is the smallest object whose height can be measured with the instruments which are at present at our command? is in general difficult to answer. According to the report of Dr. Robinson upon the beautiful reflecting telescope of Lord Rosse, extents of 220 feet (80 to 90 yards) are discerned with the greatest distinctness. Mädler calculates, that in his observations shadows of 3″ were capable of being measured, a length which, under certain presuppositions as to the position of a mountain, and the altitude of the Sun, would indicate a mountain elevation of 120 feet. However, he points out, at the same time, that the shadows must have a certain degree of breadth, in order to be visible and measurable. The shadow of the great pyramid of Cheops,

Attention has been repeatedly, and with justice, directed to the fact, that in the absence of water upon the Moon (even the *rills*, very narrow mostly rectilinear hollows,[49] are not rivers), we must represent to ourselves the surface of the Moon as being somewhat similarly constituted as was the Earth in its primitive and most ancient condition, while yet uncovered flötz strata, by *boulders* and *detritus*, which were spread out by the transporting force of the ebb and flood or *currents*. Sun and Earth floods are naturally wanting; where the liquid element is absent, slight coverings of decomposed conglomerates are scarcely conceivable. In our mountain-chains, upheaved upon fissures, partial groups of elevations are begining gradually to be discovered here and there, forming, as it were, egg-shaped basins. How entirely different the Earth's surface would have appeared to us if it were divested of the flötz and tertiary formations!

The Moon, by the variety of its phases, and the more rapid change of its relative position in the sky, animates and beautifies the aspect of the firmament under every zone more

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according to the known dimensions of this monument (superficial extent) would be, even at the point of commencement, scarcely one-ninth of a second broad, and consequently invisible. (Mädler, in Schumacher's *Jahrbuch* for 1841, p. 264.) Arago calls to mind, that with a 6,000-fold magnifying power, which, nevertheless, could not be applied to the Moon with proportionate results, the mountains upon the Moon would appear to us just as Mont Blanc does to the naked eye when seen from the Lake of Geneva.

[49] The rills do not occur frequently; are at the utmost thirty miles long; sometimes forked (Gassendi); seldom resembling mineral veins (Triesnecker); always luminous; do not cross mountains transversely; are peculiar to the level landscapes; are not characterized by any peculiarities at the terminal points, without becoming broader or narrower. (Beer and Mädler, pp. 131, 225, and 249.)

than all the other planets. She sheds her agreeable light upon men, more especially in the primitive forests of the tropical world, and the beasts of the forests.[80] The Moon, in

[80] See my Essay upon the *Nocturnal Life of Animals in the Primæval Forest*, in the *Views of Nature*, Bohn's ed. p. 198.—Laplace's reflections upon a perpetual moonlight (*Exposition du Système du Monde*, 1824, p. 232) have met with a disproval in the *Mém. of Liouville sur un cas particulier du problem des Trois Corps*. Laplace says: "Quelques partisans des causes finales ont imaginé que la Lune a été donnée à la Terre pour l'éclairer pendant les nuits; dans ce cas, la nature n'aurait point atteint le but qu'elle se serait proposé, puisque nous sommes souvent privés à la fois de la lumière du Soleil et de celle de la Lune. Pour y parvenir, il eût suffi de mettre à l'origine la Lune en opposition avec le Soleil dans le plan même de l'écliptique, à une distance égale à la centième partie de la distance de la Terre au Soleil, et de donner à la Lune et à la Terre des vitesses parallèles et proportionnelles à leurs distances à cet astre. Alors la Lune, sans cesse en opposition au Soleil, eût décrit autour de lui une ellipse semblable à celle de la Terre; ces deux astres se seraient succédé l'un à l'autre sur l'horizon; et comme à cette distance la Lune n'eût point été éclipsée, sa lumière aurait certainement remplacé celle du Soleil." "Several partizans of final causes have imagined that the Moon has been given to the Earth to light it during the night; in that case, nature would not have attained the object which she had proposed, because we are frequently deprived at the same time of the light of the Sun and Moon. To have attained this end, it would have been sufficient in the beginning to place the Moon in opposition with the Sun, in the same plane of the ecliptic, at a distance equal to the hundredth part of the distance of the Earth from the Sun, and to give to the Moon and the Earth velocities parallel and proportional to their distances from that body. Then the Moon, constantly in opposition to the Sun, would have described an ellipse round it like that of the Earth; these two bodies would have succeeded each other in the horizon. and as at that distance the Moon would never have been eclipsed, its light would certainly have replaced

virtue of the attractive force which she exercises in common with the Sun, excites motion in our ocean—the liquid portion of the Earth—gradually changes the surface by periodical floods, and the outlines of continental coasts, by the destructive agency of the tides, hinders or favours the labour of men; affords the greater part of the material from which sandstones and conglomerates are formed, and which are again covered by the rounded, loose transported detritus.[51] Thus the Moon, as one of the sources of motion, continues to act upon the geognostic relations of our planet. The indisputable[52] influence of the satellite upon atmospheric pressure,

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that of the Sun." Liouville finds, on the contrary: "Que, si la Lune avait occupé à l'origine la position particulière que l'illustre auteur de la *Mécanique Céleste* lui assigne, elle n'aurait pu s'y maintenir que pendant un tems très court." "That if the Moon had occupied at the beginning the particular position assigned to her by the illustrious author of the *Mécanique Céleste*, she would not have been able to maintain it for more than a very short time."

[51] *On the Transporting Power of the Tides*, see Sir Henry de la Beche, *Geological Manual*, 1833, p. 111.

[52] Arago, *Sur la question de savoir si la Lune exerce sur notre Atmosphère une influence appréciable*, in the *Annuaire* for 1833, pp. 157–206. The principal advocates of this opinion are Scheibler (*Untersuch. über Einfluss des Mondes auf die Veränderungen in unserer Atmosphäre*, 1830, p. 20); Flangergues (*Zwanzigjährige Beobachtungen in Viviers*, *Bibl. Universelle, Sciences et Arts*, tom. xl. 1829, pp. 265–283, and in *Kastner's Archiv f. die ges. Naturlehre*, Bd. xvii. 1829, secs. 32–50): and Eisenlohr (*Poggend. Annalen der Physik*, Bd. xxxv. 1835, pp. 141–160, and 309–329). Sir John Herschel considers it very probable that a very high temperature prevails upon the Moon (far above the boiling-point of water), as the surface is uninterruptedly exposed for fourteen days to the full action of the Sun. Therefore, in the opposition, or some few days after, the Moon must be, in some small degree, a source of heat for the Earth; but this

aqueous depositions, and the dispersion of clouds, will be treated of in the last and purely telluric part of the *Cosmos*.

Mars.

The diameter of this planet, notwithstanding its considerably greater distance from the Sun, is only 0·519 of the Earth's, or 3,568 geographical miles. The *excentricity* of his orbit is 0·0932168, next to Mercury, the greatest of all the planetary orbits; and also on this account, as well as from its proximity to the Earth, the most suitable for Kepler's great discovery of the elliptical form of the planetary orbits. *His period of rotation*[83] is, according to Mädler and Wilhelm

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heat radiating from a body far below the temperature of ignition, cannot reach the surface of the Earth, since it is absorbed in the upper strata of our atmosphere, where it converts visible clouds into transparent vapour." The phenomenon of the rapid dispersion of clouds by the full Moon, when they are not extremely dense, is considered by Sir John Herschel, "as a meteorological fact, which," he adds, "is confirmed by Humboldt's own experience and the universal belief of the Spanish sailors in the tropical seas of America. See *Report of the Fifteenth Meeting of the British Association for the Advancement of Science*, 1846, *Notices*, p. 5; and *Outlines*, p. 201.

[83] Beer and Mädler, *Beiträge zur Phys. Kenntniss des Sonnensystems*, 1841, p. 113, from observations in 1830 and 1832; Mädler, *Astronomie*, 1849, p. 206. The first considerable improvement in the data for the period of rotation, which Dominique Cassini found 24h. 40m., was the result of laborious observations by William Herschel (between 1777 and 1781) which gave 24h. 39m. 21·7s. Kunowsky found, in 1821, 24h. 36m. 40s., very near to Mädler's result. Cassini's oldest observation of the rotation of a spot upon Mars (Delambre, *Hist. de l'Astron. Mod.* tom. ii. p. 694), appears to have been soon after the year 1670; but in the very rare

Beer, 24h. 37m. 23s. *His sidereal revolution* round the Sun. occupies 1 year 321d. 17h. 30m. 41s. The *inclination of Mars' orbit* towards the Earth's equator, is 24° 44′ 24″; his mass, $\frac{1}{2680337}$; his *density*, in comparison to that of the Earth, 0·958. The mass of Mars will be hereafter corrected by means of the disturbances which he may experience from his influence with the Comet of De Vico, in the same way that the close approach of Encke's Comet was taken advantage of to ascertain the mass of Mercury.

The flattening of Mars, which (singularly enough) the great Königsberg astronomer permanently doubted, was first recognized by William Herschel (1784). With regard to the amount of the flattening, however, there was long considerable uncertainty. It was stated by William Herschel to be $\frac{1}{16}$; according to Arago's more accurate measurement,[64] with one of Rochon's prismatic telescopes, in the first instance (before 1824), only in the proportion of 189 : 194, *i. e.* $\frac{1}{38\cdot 8}$; by a subsequent measurement (1847), $\frac{1}{32}$; still Arago is inclined to consider the flattening somewhat greater.

If the study of the Moon's surface calls to mind many *geognostic* relations of the surface of the Earth; so, on the contrary, the analogies which Mars presents with the Earth, are entirely of a *meteorological* nature. Besides the dark spots,—some of which are blackish, others, though in very small numbers, yellowish-red,[65] and surrounded by the greenish

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Treatise, Kern, *Diss. de Scintillatione Stellarum*, Wittenb. 1686, § 8, I find that the actual *discoverers of the rotations of Mars and Jupiter* are stated to have been "Salvator Serra and Father Ægidius Franciscus de Cottignez, astronomers of the Collegio Romano."

[64] Laplace, *Expos. du Syst. du Monde*, p. 36. Schröter's very imperfect measurement of the diameter of the planet gave Mars a flattening of only $\frac{1}{80}$.

[65] Beer and Mädler, *Beiträge*, p. 111.

contrast colours, so-called seas;[56]—there are seen upon the disc of Mars two white, brilliant, snow-like spots,[57] either at the poles which are determined by the axis of rotation, or at the poles of cold alternately. They were recognized, as early as 1716, by Philip Maraldi, though their connection with climatic changes upon the planet was first described by the elder Herschel, in the seventy-fourth volume of the *Philosophical Transactions* for 1784. The white spots become alternately larger or smaller, according as the poles approach their winter or summer. Arago has measured, by means of his polariscope, the intensity of the light of these *snow zones*, and found it twice as great as that of the remaining part of the disc. The *Physikalisch-astronomische Beiträge* of Mädler and Beer, contain some excellent graphic representations[58] of the north and south hemispheres of Mars; and this remarkable phenomenon, unparalleled throughout the whole planetary system, is there investigated with reference to all the changes of seasons, and the powerful action of the polar summer upon the melting snow. Careful observations, during a period of ten years, have also taught us that the dark spots upon Mars preserve a constant form and relative position. The periodical formation of *snow-spots*, as meteoric depositions dependent upon change of temperature, and some optical phenomena which the dark spots present as soon as they have, by the rotation of the planet, reached the edge of the disc, make the existence of an atmosphere upon Mars more than probable.

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[56] Sir John Herschel, *Outlines*, § 510.
[57] Beer and Mädler. *Beiträge*, pp. 117–125.
[58] Mädler, in Schumacher's *Astr. Nachr.* no. 192.

The Small Planets.

We have already, in the general consideration[59] of the planetary bodies, characterized the group of *small planets*

[59] *Cosmos*, vol. iv. p. 422. With regard to the chronology of the discoveries of the small planets, compare pp. 421 and 462; their relations of magnitude to the meteor-asteroids (aërolites), p. 427. With respect to Kepler's conjecture of the existence of a planet in the great chasm between Mars and Jupiter; a conjecture, however, which by no means led to the discovery of the first of the small planets (*Ceres*), p. 435 and notes 31–33. The bitter reproach which has been thrown upon a highly esteemed philosopher, "because at a time when he might have known of Piazzi's discovery certainly five months before, but was unacquainted with it, he denied not so much the probability, as much more the necessity of a planet being situated between Mars and Jupiter," appears to me to be little justifiable. Hegel, in his *Dissertatio de Orbitis Planetarum*, composed in the spring and summer of 1801, treats of the ideas of the ancients of the distances of the planets: and when he quotes the arrangement of which Plato speaks in the *Timæus*, (p. 35, Steph.); 1 . 2 . 3 . 4 . 9 . 8 . 27 . . . . . (compare *Cosmos*, vol. iv. p. 432, note 21) he denies the necessity of a chasm. He says only: "Quæ series *si verior naturæ ordo sit*, quam arithmetica progressio, inter quartum et quintum locum magnum esse spatium, neque ibi planetam desiderari apparet." "If the order of nature is more precise than an arithmetical progression, there appears to be a great space between the fourth and fifth place, and that no planet is required there." (Hegel's *Werke*, Bd. xvi. 1834, p. 28; and Hegel's *Leben von Rosenkranz*, 1844, p. 154.) Kant, in his ingenious work, *Naturgeschichte des Himmels*, 1755, says merely that at the time of the formation of the planets, Jupiter occasioned the *smallness* of Mars, by the enormous attractive force which the former possessed. He only once mentions, and then in a very indecisive manner, "the members of the solar system which are situated far from each other, and between which the intermediate parts have not yet been discovered." (Immanuel Kant, *Sämmtliche Werke*, Th. vi. 1839, pp. 87, 110, and 196.)

(*asteroids, planetoids, co-planets, telescopic* or *ultra-zodiacal planets*) under the name of an *intermediate group*, which, to a certain extent, forms a zone of *separation* between the 4 *interior planets* (Mercury, Venus, the Earth, and Mars), and the 4 *exterior* planets of our solar system (Jupiter, Saturn, Uranus, and Neptune). Their most distinctive features consist in their interlaced, greatly inclined, and extremely excentric orbits; their extraordinary smallness, as the diameter of Vesta does not appear to equal even the fourth part of the diameter of Mercury. When the first volume of the *Cosmos* appeared (1845), only 4 of the small planets were known: Ceres, Pallas, Juno, and Vesta, discovered by Piazzi, Olbers, and Harding (between January 1, 1801, and March 29, 1807); at the present time (July, 1851), the number of the small planets has already increased to 14; they form numerically the third part of all the 43 known planetary bodies, *i. e.* of all principal and secondary planets.

Although the attention of astronomers was long directed in the solar regions to increasing the number of the members of partial systems—the Moons which revolve round principal planets—and to the planets to be discovered in the furthest regions beyond Saturn and Uranus; now since the accidental discovery of Ceres by Piazzi, and especially since the foreseen discovery of Astrea by Encke, as well as the great improvements in the star-charts[60] (those of the Berlin Academy contain all stars as far as the 9th, and partly to the 10th magnitudes), a nearer space presents to us the richest, and perhaps inexhaustible field for astronomical industry. It is an especial merit of the *Astronomische Jahrbuch*, which is published in my native town by Encke, the Director of the

[60] With regard to the influence of improved star-charts upon the discovery of the small planets, see *Cosmos*, vol. iii. pp. 155 and 156.

Berlin Observatory, with the assistance of Dr. Wolfers, that the ephemerides of the increasing host of small planets are treated of with particular completeness. Up to the present time, the region nearest to the orbit of Mars appears to be the most filled; but the breadth of this measured zone is, in itself, more considerable than the distance of Mars from the Sun.[61] "when the difference of the radii-vectores in the nearest perihelion (Victoria), and the most distant aphelion (Hygiea), is taken into consideration."

The excentricities of the orbits, of which those of Ceres, Egeria, and Vesta are the smallest, and Juno, Pallas, and Iris the greatest, have already been alluded to[62] above, as well as their degrees of inclination towards the ecliptic, which decreases from Pallas (34° 37′), and Egeria (16° 33′), to Hygiea (3° 47′). A tabular view of the elements of the small planets follows here, for which I am indebted to my friend Dr. Galle.

The discovery of a fifteenth new planet (*Eunomia*) has just been announced. It was discovered by De Gasparis upon the 19th of July, 1851. The elements, which have been calculated by Rümker, are the following:—

Epoch of mean longitude in mean Greenwich time ...	1851. Oct. 1·0
Mean longitude	321° 25′ 29″
Longitude of perihelion	27 35 38
Longitude of ascending node	293 52 55
Inclination	11 48 43
Excentricity	0·188402
Half major axis	2·64758
Mean of motion	823·630
Period of revolution	1574 days.

[61] D'Arrest, *Ueber das System der Kleinen Planeten zwischen Mars und Jupiter*, 1851, p. 8.

[62] *Cosmos*, vol. iv. pp. 423 and 456.

Elements of the 14 Small Planets, for the Periods of their Oppositions about the Year 1851.

	Flora.	Victoria.	Vesta.	Iris.	Metis.	Hebe.	Parthenope.	Astrea.	Egeria.	Irene.	Juno.	Ceres.	Pallas.	Hygeia.
	1852	1850	1851	1851	1851	1851	1851	1851	1852	1851	1851	1851	1851	1851
E	March 24	Oct. 0	June 9	Oct. 1	Feb. 8.	July 12	Oct. 22 0	Apr. 29·5	March 15·0	July 1·0	June 11·5	Dec. 30·0	Nov. 5·0	Sept. 28·5
L	174° 45′	342° 18′	256° 38′	18° 36′	126° 28′	311° 39′	17° 51′	197° 37′	162° 29′	234° 15′	276° 0′	105° 33′	72° 35′	356° 45′
π	32 51	301 57	250 32	41 22	71 7	15 17	317 5	135 43	118 17	179 10	54 20	147 59	121 23	228 2
☊	110 21	235 28	103 22	259 44	68 29	138 31	124 59	141 28	43 18	86 51	170 55	80 49	172 45	287 38
i	5 53	8 23	7 8	5 28	5 36	14 47	4 37	5 19	16 33	9 6	13 3	10 37	34 37	8 47
μ	1086″·04	994″·51	977″·90	963″·03	962″·58	939″·65	926″·22	857″·50	854″·96	853″·77	813″·88	770″·75	768″·13	634″·24
a	2·2018	2·3349	2·3612	2·3855	2·3862	2·4249	2·4483	2·5774	2·5825	2·5849	2·6687	2·7673	2·7729	3·1514
e	0·15679	0·21792	0·08692	0·23239	0·12229	0·20186	0·09789	0·18875	0·08627	0·16786	0·25586	0·07647	0·23956	0·10092
U	1193d.	1303d.	1325d.	1346d.	1346d.	1379d.	1399d.	1511d.	1516d.	1518d.	1592d.	1681d.	1687d.	2043d.

The letters represent: E, the epoch of mean longitude in mean Berlin time; L, the mean longitude in the orbit; π, the longitude of the perihelion; ☊, the longitude of the ascending node; i, the inclination to the ecliptic; μ, the mean daily sidereal motion; a, the half major axis; e, the excentricity; U, the period of sidereal revolution in days.—The longitudes refer to the equinox of the epoch.

The mutual relation of the orbits of the asteroids and the enumeration of the individual *pairs of orbits*, has been made the subject of acute investigation, first by Gould[63] in 1848, and more recently by D'Arrest. The latter says, "The strongest evidence of the intimate connection of the whole group of small planets appears to be, that if the orbits are supposed to be represented materially as hoops, they all hang together in such a manner that the whole group may be suspended by any given one. If it so happened that Iris, which Hind discovered in August, 1847, was still unknown, as many other bodies in this region certainly are, the group would consist of two separate parts,—a result which must appear so much the more unexpected as the zone which these orbits occupy in the solar system is wide."[64]

We cannot take leave of this wonderful group of planets without mentioning, in this fragmentary enumeration of the individual members of the solar system, the bold view of a gifted and deeply investigating astronomer, as to the origin of the asteroids and their intersecting orbits. A result deduced from the calculations of Gauss, that Ceres approaches extremely near to Pallas in her ascending passage through the plane of that planet's orbit, led Olbers to form the conjecture that "both planets, Ceres and Pallas, may be fragments of a single large principal planet which has been destroyed by some natural force, and formerly occupied the gap between Mars and Jupiter, and that the discovery of an additional number of similar fragments which describe elliptical orbits round the Sun, in the same region, may be expected."[65]

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[63] Benjamin Althorpe Gould (now at Cambridge, Massachusetts, U.S.) *Untersuchungen über die gegenseitige Lage der Bahnen zwischen Mars und Jupiter*, 1848, pp. 9–12.

[64] D'Arrest, *op. cit.* p. 30.

[65] Zach, *Monatl. Corresp.* Bd. vi. p. 88.

The possibility of determining by calculation, even approximatively, the epoch of such a cosmical event, which it is supposed would be at the same time the epoch of the formation of the small planets, remains more than doubtful, from the complication produced by the already large number of the "fragments" known, the secular retrogression of the apsides, and motion of the nodes.[66] Olbers describes the region of the nodes of the orbits of Ceres and Pallas, as corresponding to the northern wing of the Virgin and the constellation of the Whale. Certainly Juno was discovered, in the latter by Harding, though accidentally, in the construction of a star-catalogue, scarcely two years after the discovery of Pallas, and even Vesta, in the former after a long-search during five years, conducted upon hypothesis. This is not the place to determine whether these results alone are sufficient to establish the hypothesis. The cometary clouds, in which the small planets were at first supposed to be enveloped, have disappeared on investigation with more perfect instruments. The considerable changes of light to which they were said to be subject, were ascribed by Olbers to their irregular figure as being "fragments of a single destroyed planet."[67]

[66] Gauss, *Monatl. Corresp.* Bd. xxvi. p. 299.

[67] Mr. Daniel Kirkwood (of the Pottsville Academy) has ventured upon the undertaking of restoring the exploded primitive planet from the fragmentary remains in the same manner as the animals of the primitive Earth. He finds for it a diameter greater than Mars (of more than 4,320 geographical miles), and the slowest rotation of all the principal planets—a length of day of fifty-seven hours and a half. (*Report of the British Assoc.* 1850, p. xxxv.)

JUPITER.

The mean distance of Jupiter from the Sun, expressed in fractional parts of the Earth's distance from the central body, amounts to 5·202767. The true mean diameter of this planet, the largest of all, is 77,176 geographical miles; equal, therefore, to 11·255 terrestrial diameters, about one-fifth greater than the diameter of the more remote Saturn. His sidereal revolution occupies 11y. 314d. 20h. 2m. 7s.

The flattening of Jupiter, according to the measurements by Arago with the prismatic micrometer (which were introduced into the *Exposition du Système du Monde*, p. 38), is as 167 : 177, consequently $\frac{1}{17\cdot7}$, which agrees very closely with the later determination (1839) of Beer and Mädler,[68] who found the flattening to be between $\frac{1}{18\cdot7}$ and $\frac{1}{21\cdot6}$. Hansen and Sir John Herschel give the preference to $\frac{1}{14}$. The earliest observation of the flattening, by Dominique Cassini, is older than the year 1666, as I have already pointed out elsewhere. This circumstance has an especial historical importance, on account of the influence which, according to Sir David Brewster's acute remark, the discovery of this flattening by Cassini exercised upon Newton's ideas as to the figure of the Earth. The *Principia Philosophiæ Naturalis* bears witness to this, but the epochs at which the *Principia* and Cassini's observation of equatorial and polar diameters of Jupiter appeared, might excite chronological doubts.[69]

[68] Beer and Mädler, *Beiträge zur Phys. Kenntniss der Himl. Körper*, pp. 104–106. Older and less certain observations by Hussey gave $\frac{1}{24}$. Laplace (*Syst. du Monde*, p. 266) found it theoretically between $\frac{1}{24}$ and $\frac{5}{48}$, with increasing density of the strata.

[69] Newton's immortal work, *Philosophiæ Naturalis Principia Mathematica*, appeared as early as May, 1687, and the

As the mass of Jupiter after that of the Sun is the most important element of the whole planetary system, its accurate determination, which has recently been effected through the disturbances of Juno and Vesta, as well as by the elongation of his satellites, especially the fourth,[70] must be considered as one of the most productive improvements of calculating astronomy. The value of the mass of Jupiter is greater now than formerly; that of Mercury, on the contrary, smaller. The former, together with that of the four satellites, is $\frac{1}{1047 \cdot 879}$, while Laplace gave it as $\frac{1}{1066 \cdot 09}$[71].

Jupiter's *period of rotation* is, according to Airy, 9h. 55′ 21″·3 mean solar time. Dominique Cassini first found it (1665) to be between 9h. 55m. and 9h. 56m., by means of a spot which was visible[72] for many years, even indeed to 1691, and was always of the same colour and outline. The greater part of these spots are of greater blackness than the streaks upon Jupiter. They do not, however, appear to belong to the surface of the planet itself, as they sometimes have a different velocity from that of the equatorial regions. According to a very experienced observer, Heinrich Schwabe of Dessau, the dark, more sharply bounded spots have been

papers of the Paris Academy did not contain the notice of Cassini's determination of the flattening ($\frac{1}{15}$) until the year 1691; so that Newton, who might certainly have known of Richer's pendulum-experiment at Cayenne, from the account of the journey printed in 1679, must have become acquainted with the configuration of Jupiter by verbal intercourse and the active correspondence of that time. With regard to this subject, and the only apparent early acquaintance of Huygens with the pendulum-experiment of Richer, compare *Cosmos*, vol. i. p. 156, note; and vol. ii. p. 136, note.

[70] Airy, in the *Mem. of the Royal Astron. Soc.* vol. ix. p. 7; vol. x. p. 43.

[71] As early as the year 1824. (Laplace, *op. cit.* p. 207.)

[72] Delambre, *Hist. de l'Astron. mod.* tom. ii. p. 754.

several years in succession exclusively peculiar to the two grey girdles bordering upon the equator, sometimes the north and sometimes the south. The process of spot-formation is, therefore, locally variable. Schwabe's observations, made in November, 1834, likewise show that the spots on Jupiter seen with a 280-fold magnifying power in a Fraunhofer telescope, sometimes resemble the small nucleoid spots surrounded by a halo upon the Sun. But still their darkness is less than that of the satellite shadows. The nucleus is probably a part of the body of Jupiter itself, and if the atmospheric opening remains fixed above the same spot, the motion of the spots gives the true rotation. They also separate sometimes, like the Sun-spots, as Dominique Cassini discovered as early as 1665.

In the equatorial zone of Jupiter are situated two broad *principal streaks* or *girdles*, of a grey or greyish-brown colour, which become paler towards the edges, and finally disappear entirely. Their boundaries are very irregular and variable: both are separated by an intermediate bright equatorial streak. Towards the poles also the whole surface is covered with numerous, narrower, paler, frequently interrupted, even finely branched streaks, always parallel to the equator. "These phenomena," says Arago,[73] "are most easily explain-

[73] "On sait qu'il existe au-dessus et au-dessous de l'équateur de Jupiter deux bandes moins brillantes que la surface générale. Si on les examine avec une lunette, elles paraissent moins distinctes à mesure qu'elles s'éloignent du centre, et même elles deviennent tout-à-fait invisibles près des bords de la planète. Toutes ces apparences s'expliquent en admettant l'existence d'une atmosphère de nuages interrompue aux environs de l'équateur par une zone diaphane, produite peut-être par les vents alisés. L'atmosphère de nuages réfléchissant plus de lumière que le corps solide de Jupiter, les parties de ce corps que l'on verra à travers la zone diaphane, auront

able by assuming the existence of an atmosphere partially obscured by strata of clouds, in which, however, the region resting upon the equator is free from vapour and diaphanous

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moins d'éclat que le reste et formeront les bandes obscures. A mesure qu'on s'éloignera du centre, le rayon visuel de l'observateur traversera des épaisseurs de plus en plus grandes da la zone diaphane, en sorte qu'à la lumière réfléchie par le corps solide de la planète s'ajoutera la lumière réfléchie par cette zone plus épaisse. Les bandes seront par cette raison moins obscures en s'éloignant du centre. Enfin aux bords mêmes la lumière réfléchie par la zone vue dans la plus grande épaisseur pourra faire disparaître la différence d'intensité qui existe entre les quantités de lumière réfléchie par la planète et par l'atmosphère de nuages; on cessera alors d'apercevoir les bandes qui n'existent qu'en vertu de cette différence. On observe dans les pays de montagnes quelque chose d'analogue: quand on se trouve près d'un forêt de sapin, elle paraît noire; mais à mesure qu'on s'en éloigne, les couches d'atmosphère interposées deviennent de plus en plus épaisses et réfléchissent de la lumière. La différence de teinte entre la forêt et les objets voisins diminue de plus en plus, elle finit par se confondre avec eux, si l'on s'en éloigne d'une distance convenable." (From Arago's *Reports on Astronomy*, 1841.) "It is known that there exist above and below the equator of Jupiter two bands less brilliant than the general surface. If these are examined with a telescope, they appear less distinct in proportion as the distance from the centre increases, and they even become quite invisible near the edges of the planet. All these appearances may be explained by admitting the existence of an atmosphere of clouds, interrupted near the equator by a transparent zone, produced, perhaps, by the trade-winds. The atmosphere of clouds reflects more light than the solid body of Jupiter. Those parts of him which are seen through the transparent zone would have less brightness than the remainder, and would form obscure bands. In proportion as the distance from the centre increases, the visual ray of the observer traverses greater and greater thicknesses of the transparent zone, in such a way that to the light reflected by the solid

probably in consequence of the trade-winds. Since, as William Herschel already assumed in a treatise in the 83rd vol. of the *Philosophical Transactions*, which appeared in 1793, the cloud-surface reflects a more intense light than the surface of the planet, so that part of the ground which we see through the clearer air must have less light (appear darker) than the strata of clouds reflecting large quantities of light. On that account grey (dark) and clear bands alternate with each other; the former appear so much the less dark-coloured in proportion to the distance from the centre, when, the visual radius of the observer being directed obliquely towards the edge of the planet, at a small angle, they are seen through a larger and thicker mass of atmosphere, reflecting more light.

The Satellites of Jupiter.

Even so early as the brilliant epoch of Galileo the correct opinion was formed, that the *subordinate planetary system* of Jupiter might present, in many relations of space and

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body of the planet is added the light reflected by the denser zone. The bands would be, from this reason, less obscure the greater the distance from the centre. Finally, at the very edges of the planet's disc the light reflected by the zone seen in its greatest thickness, would cause the difference of intensity which existed between the quantities of light reflected by the planet and by the atmosphere of clouds, to disappear, and the bands which exist only in virtue of that difference would cease to be visible. Something analogous is observed in mountainous countries; in the neighbourhood of a forest of fir-trees they appear black, but in proportion as the observer removes to a greater distance, the interposed atmospheric strata become thicker and thicker, and reflect light. The difference of tint between the forest and the objects near, diminishes more and more, and ends by their being confounded together on removing to a sufficient distance."

time, a picture in miniature of the Solar System. This view, rapidly diffused at that time, as well as the discovery, shortly afterwards, of the phases of Venus (February, 1610), contributed greatly to the general introduction of the Copernican system. The quadruple group of satellites of Jupiter, is the only one of the exterior principal planets which has not been increased by any new discovery, during a period of nearly two centuries and a half, since the epoch of their first discovery by Simon Marius on the 29th of December, 1609.

The following table contains the *periods of sidereal revolution* of the satellites of Jupiter, their *mean distances* expressed in diameters of the primary, their *diameters* in geographical miles, and their *masses* as parts of the mass of Jupiter.

Satellites.	Period of Revolution.	Distance from Jupiter.	Diameter in geogr. miles.	Mass.
	d. h. m.			
1	1 18 28	6,049	2116	0·0000173281
2	3 13 14	9,623	1900	0·0000232355
3	7 3 14	15,350	3104	0·0000884972
4	16 16 32	26,998	2656	0·0000426591

If $\frac{1}{1047\cdot879}$ expresses the mass of Jupiter with his satellites, then his mass without the satellites is $\frac{1}{1048\cdot059}$, only about $\frac{1}{6000}$ smaller.

The comparisons of the *magnitudes, distances*, and *excentricities* with other satellite systems. has already been given (*Cosmos*, vol. iv. pp. 426–457). The *luminous intensity* of Jupiter's satellites is various, and not in proportion to their volume, since, as a general rule, the *third* and the *first*, whose relation of magnitude is as 8 : 5, appear the brightest. The smallest and densest of all—the *second*—is generally brighter than the larger *fourth*, which is ordinarily called the *least luminous*. Accidental (temporary) fluctuations in the luminous

intensity have, as already remarked, been ascribed sometimes to changes of the surface, sometimes to obscurations in the atmosphere of the satellites.[75] They all appear moreover to reflect a more intense light than the primary. When the Earth is situated between Jupiter and the Sun, and the satellites therefore moving from east to west, apparently enter on the eastern edge of Jupiter, they hide from us, in their passage, successive portions of the disc of their primary, and can be perceived with telescopes of moderate power. since they stand out in *luminous relief* from the disc. The visibility of the satellite is attended with more difficulty the nearer it approaches the centre of the primary. From this phenomenon, which was early observed, Pound, Newton's and Bradley's friend, inferred that the disc was less luminous near the edge than at the centre. Arago considers that this assumption, renewed by Messier, involves difficulties which can only be solved by new and more delicate observations. Jupiter was seen without any satellites by Molyneux in November, 1681; by Sir William Herschel on the 23rd of May, 1802; and, lastly, by Griesbach, on the 27th of September, 1843. Such a non-visibility of the satellites has reference however to the space *without* the disc of Jupiter, and is not inconsistent with the theorem that all the four satellites cannot be *eclipsed* at one time.

SATURN.

The *period* of sidereal or true *revolution* of Saturn is 29 years, 166d. 23h. 16m. 32s. His mean diameter is 62,028 geographical miles, equal to 9,022 terrestrial diameters. The period of *rotation* deduced from the observation of some dark spots (knot-like condensations of the bands) upon the sur-

[75] Sir John Herschel, *Outlines*, § 540.

tance,[76] is 10h. 29m. 17s. Such a great velocity of rotation corresponds to the considerable *flattening*. William Herschel estimated it, in 1776, at $\frac{1}{10 \cdot 4}$; Bessel, after corresponding observations during a period of more than three years, found that at a mean distance the polar diameter was 15″·381; the equatorial diameter 17″·053, consequently a flattening of $\frac{1}{10 \cdot 2}$.[77] The body of the planet has also riband-like *stripes*, which are however less perceptible, though, at the same time, rather broader than those of Jupiter. The most constant of them is a grey *equatorial stripe*. Next to this follow several others,

[76] The earliest and careful observations of William Herschel, in November, 1793, gave for Saturn's period of rotation 10h. 16m. 44s. It has been incorrectly attributed to the great philosopher, Immanuel Kant, that he conjectured the period of Saturn's rotation from theoretical considerations in his *Allgemeinen Naturgeschichte des Himmels*, forty years before Herschel. The number that he gives is 6h. 23m. 53s. He calls his determination "the mathematical calculation of an unknown motion of a heavenly body, which is perhaps the *only prediction* of that kind in pure Natural Philosophy, and awaits confirmation at a future period." This confirmation of his conjecture did not take place at all; observations have shown an error of $\frac{2}{5}$ of the whole, *i. e.* of four hours. In the same work it is said respecting the ring of Saturn, "that in the aggregation of particles which constitute it, those of the inner edge complete their revolution in 10 hours, those of the external edge in 15 hours. The first of these ring-numbers is the only one which accidentally comes near the planet's observed period of rotation (10 d. 29m. 17s.). Compare Kant, *Sämmtliche Werke*, Th. vi. 1389, pp. 135 and 140.

[77] Laplace (*Expos. du Syst. du Monde*, p. 43,) estimates the flattening at $\frac{1}{11}$. The extraordinary deviation of Saturn from the spheroidal figure, according to which William Herschel, after a series of laborious observations made with very different telescopes, found the major axis of the planet not in the equator itself, but in a diameter which intersected the equatorial diameter at an angle of about 45°, was not confirmed by Bessel, but found to be incorrect.

but with *variable* forms, indicating an atmospheric origin. William Herschel did not always find them parallel to the rings; neither do they extend as far as the poles. The region round the poles presents a very remarkable phenomenon, a change in the reflection of light which is dependent upon Saturn's seasons. This region is more brightly luminous in winter, a phenomenon which calls to mind the variable snow-region of Mars, and did not escape the penetration of William Herschel. Whether such an increase of luminous intensity is to be ascribed to the temporary formation of ice and snow, or to an extraordinary accumulation of clouds,[78] it is still indicative of the action of changes in temperature, and of the existence of an atmosphere.

We have already stated the mass of Saturn to be $\frac{1}{3501.6}$; it, together with the enormous volume of the planet (its diameter is $\frac{4}{5}$ of the diameter of Jupiter), leads us to infer a very small density decreasing towards the surface. If the density were quite homogeneous ($\frac{76}{100}$ of that of water), the flattening would be still greater.

The planet is surrounded in the plane of its equator with at least two fully suspended and extremely thin rings, both situated in the same plane. Their luminous intensity is greater than that of Saturn itself, and the outer ring is still brighter than the inner.[79] The division of the ring seen by Huygens in 1655, as a single one,[80] was indeed observed by Dominique Cassini in 1675, but first accurately described by William Herschel in 1789–1792. Since Short's time the outer has been found to be streaked by numerous fine stripes,

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[78] Arago, *Annuaire* for 1842, p. 555.

[79] This difference in the luminous intensity of the outer and inner rings was also stated by Dominique Cassini (*Mém. de l'Académie des Sciences*, année 1715, p. 13).

[80] *Cosmos*, vol. ii. p. 705. The *public announcement* of the discovery, or rather the complete explanation of all the phe-

but these lines or stripes have never been constant. Very recently, during the latter months of the year 1850, a third very pale, feebly luminous, and *darker ring*, has been discovered between the planet and the ring hitherto called the inner one. The discovery was made nearly simultaneously by Bond, at Cambridge (U. S.), on the 11th of November, by means of the great refractor of Mertz with a fourteen-inch object-glass, and by Dawes, near Maidstone, on the 25th of November. This ring is separated from the second by a black line, and occupies the third part of the space, between the second ring and the body of the planet, which was formerly stated to be vacant, and through which Derham affirmed that he saw small stars.

The dimensions of the divided ring of Saturn have been determined by Bessel and Struve. According to the latter, the exterior diameter of the outer ring, at Saturn's mean distance, appears to us under an angle 40″·09, equal to 153,200 geographical miles; the interior diameter of the same ring under an angle of 35″·29, equal to 134,800 geographical miles. For the exterior diameter of the inner (second) ring is obtained 31″·47; for interior diameter of the same ring 26″·67. Struve fixes the space between the last-mentioned ring and the surface of the planet at 4″·34. The entire breadth of the first and second rings is 14,800 miles; the distance of the rings from the surface of Saturn, about 20,000; the space which separates the first from the second ring, and which represents the black line of division seen by Dominique Cassini, is only 1,560 miles. The mass of the rings is, according to Bessel, $\frac{1}{118}$ of the mass of Saturn. They present a few elevations[81]

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nomena which are presented by Saturn and his ring, did not take place until the year 1659, four years afterwards, in the *Systema Saturnium*.

[81] Such mountain-like inequalities of surface have recently been again noticed by Lassell in Liverpool, by means of a

and irregularities, by means of which it *has* been possible to determine approximatively their period of rotation—exactly the same as that of the planet. The irregularities of form become perceptible on the *disappearance of the rings*, when one is generally lost sight of before the other.

A very remarkable phenomenon was discovered by Schwabe, at Dessau, in September, 1827,—the *excentric position* of Saturn. The ring is not concentric with the planet itself, but the latter is situated somewhat to the westward. This observation has been confirmed—partly by micrometrical measurements—by Harding, Struve,[82] John Herschel, and South. The small differences in the degree of excentricity, appearing periodically, which result from the corresponding observations of Schwabe, Harding, and De Vico in Rome, are perhaps consequences of oscillations of the centre of gravity of the ring about the geometrical centre of Saturn. It is surprising that so early as the end of the seventeenth century, a priest of Avignon, named Gallet, attempted unsuccessfully to direct the attention of astronomers to the excentric position of Saturn.[83]

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twenty-feet reflecting telescope of his own construction. *Report of the British Association*, 1850, p. 35.

[82] Compare *Harding's Kleine Ephemeriden* for 1835, p. 100; and Struve, in Schumacher's *Astr. Nachr.* No. 139, p. 389.

[83] In the *Actis Eruditorum pro anno* 1684, p. 424, is as an extract from the *Systema Phænomenorum Saturni*, autore Galletio, proposito eccl. Avenionensis: "Nonnunquam corpus Saturni *non exacte annuli medium* obtinere visum fuit. Hinc evenit, ut, quum planeta orientalis est, centrum ejus extremitati orientali annuli propius videatur, et major pars ab occidentali latere sit cum ampliore obscuritate." "Sometimes the mass of Saturn appeared not to reach *exactly the middle of his ring*. Hence it happens that when that planet is in the east his centre appears nearer to the eastern extremity of the ring, and the greater part is away from the western side with greater obscurity."

With the extremely minute density of Saturn (perhaps scarcely ⅞ the density of water) and its decrease towards the surface, it is difficult to form a conception of the *molecular condition* or *material* constitution of the body of the planet, or even to decide whether this constitution actually presupposes fluidity, *i. e.* mobility of the smallest particles,—or solidity, according to the frequently adduced analogies of pine-wood, pumice-stone, cork, or a *solidified liquid*—ice. Horner, the astronomer of the Krusenstern expedition, calls the ring of Saturn a train of clouds; he maintains that the mountains of Saturn consist of masses of vapour.[84] Conjectural astronomy exercises here an unrestricted and tolerated play. Of an entirely different nature are the serious speculations of two distinguished American astronomers, Bond and Peirce, as to the possible *stability* of Saturn's rings, founded upon observations and the analytical calculus.[85] Both agree in their results in favour of fluidity, as well as continuous variability in the figure, and divisibility of the outer ring. The permanence of the whole is considered by Peirce as dependent upon the influence and position of the satellites, because without this dependence, *even with inequalities in the ring*, the equilibrium could not be maintained.

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[84] Horner, in Gehler's *neuem physik. Worterbuch*, Bd. viii. 1836, p. 174.

[85] Benjamin Peirce, *On the Constitution of Saturn's Ring* in Gould's *Astron. Journal*, 1851, vol. ii. p. 16. "The ring consists of a stream or of streams of a fluid rather denser than water flowing round the primary." Compare also Silliman's *Amer. Journal*, ser. ii. vol. xii. 1851, p. 99; and with regard to the superficial inequalities of the ring, as well as disturbing and consequently *preserving* influences of the satellites, Sir John Herschel, *Outlines*, p. 320.

The Satellites of Saturn.

The five satellites of Saturn which have been known longest were discovered between the years 1655 and 1684 (*Titan*, the sixth according to distance, by Huygens; and four by Cassini, viz. *Japetus*, the outermost of all, *Rhea*, *Tethys*, and *Dione*). These were followed by the discovery, by William Herschel, in 1789, of two, *Mimas* and *Enceladus*, situated nearest to the planet. Finally, the seventh satellite, *Hyperion*, the last but one according to distance, was discovered almost simultaneously by Bond, at Cambridge (U.S.), and by Lassell at Liverpool, in September, 1848. The relative magnitudes and relations of distances in this partial system have been already treated of. (*Cosmos*, vol. i. p. 81, vol. iv. pp. 426-445). The *periods of revolution* and the mean distances, the latter expressed in fractional parts of the equatorial radius of the primary, are, according to the observations instituted by Sir John Herschel, at the Cape of Good Hope,[**] between 1835 and 1837, the following:

Satellites according to the order of their discovery.	Satellites according to their distances.	Period of Revolution.				Mean Distance.
		d.	h.	m.	s.	
f	1. Mimas	0	22	37	22·9	3·3607
g	2. Enceladus	1	8	53	6·7	4·3125
e	3. Tethys	1	21	18	25·7	5·3396
d	4. Dione	2	17	41	8·9	6·8398
c	5. Rhea	4	12	25	10·8	9·5528
a	6. Titan	15	22	41	25·2	22·1450
h	7. Hyperion	22	12	?		28·0000 ?
b	8. Japetus	79	7	53	40·4	64·3590

[**] Sir John Herschel, *Results of Astron. Observations at the Cape of Good Hope*, pp. 414–430; the same, in the *Outlines of Astr.* p. 650, and upon the law of distances, § 550.

Between the first four satellites nearest to Saturn a remarkable relation of *commensurability in the period of revolution* presents itself. The period of the third satellite (*Tethys*) is double that of the first (*Mimas*); that of the fourth (*Dione*) double that of the second (*Enceladus*). The closeness of this relation extends to $\frac{1}{800}$ of the longer periods. This unnoticed result was communicated to me by Sir John Herschel in a letter as long back as 1845. The four satellites of Jupiter present a certain regularity in their distances, forming very nearly the series 3, 6, 12. The distance of the second from the first expressed in diameters of Jupiter is 3·6; the distance of the third from the second, 5·7; that of the fourth from the third, 11·6. Moreover Fries and Challis have endeavoured to prove the so-called law of Titius in all satellite systems, even in that of Uranus.[97]

Uranus.

The acknowledged existence of this planet, the great discovery of William Herschel, has not only increased the number of the principal planets known for thousands of years, and more than doubled the diameter of the solar regions,—it has also, after the lapse of sixty-five years, led to the discovery of Neptune, through the disturbances which it underwent from the influence of the latter. Uranus was discovered accidentally (13th March, 1781) during the examination of a small group of stars in Gemini by its small disc, which with magnifying powers of 460 and 932 increased far more considerably than was the case with other adjacent stars. The sagacious discoverer, so thoroughly acquainted with all *optical*

[97] Fries, *Vorlesungen über die Sternkunde*, 1833, p. 325; Challis, in the *Transact. of the Cambridge Philos. Society*, vol. iii. p. 171.

phenomena, also observed that the luminous intensity *decreased* considerably in proportion as stronger magnifying powers were employed while in the fixed stars (6th and 7th magnitude) it remained nearer the same.

When Herschel first announced the existence of Uranus he called it a *comet*, and it was only by the united labours of Saron, Lexell, Laplace, and Méchain, which were considerably facilitated by the discovery made by the meritorious Bode in 1784 of the previous observations of the planet by Tobias Mayer (1756) and Flamstead (1690), that the elliptical orbit of Uranus and the whole of its planetary elements were determined with admirable celerity. According to Hansen, the mean *distance* of Uranus from the Sun is 1,918,239 or 1586 million geographical miles; his *period of sidereal revolution*, 84 y. 5d. 19h. 41m. 36s.; the inclination of his orbit to the ecliptic, 0° 46′ 28″; his apparent *diameter* at the mean distance from the Earth, 9″·9. His *mass*, which was determined as $\frac{1}{17918}$ from the first observations of the satellites, is, according to Lamont's observations, only $\frac{1}{24605}$; consequently his *density* would be between those of Jupiter and Saturn.[89] A flattening of Uranus was already conjectured by Herschel from his observations with magnifying powers of from 800 to 2,400. According to Mädler's measurements in 1842 and 1843, it would appear to fall between $\frac{1}{10.7}$ and $\frac{1}{9.9}$.[90] The original supposition that Uranus had two rings was found to be an optical illusion by the discoverer himself, in all cases so cautious and persevering in confirming his discoveries.

[88] William Herschel, *Account of a Comet* in the *Philos. Transact.* for 1781, vol. lxxi. p. 492.

[89] *Cosmos*, vol. iv. p. 446.

[90] Mädler, in Schumacher's *Astr. Nachr.* No. 493. (With regard to the flattening of Uranus, compare Arago, *Annuaire* for 1842, pp. 577–579.)

The Satellites of Uranus.

"Uranus," says Sir John Herschel, "is attended by satellites—four at least, probably five or six." They present a great and hitherto unparalleled peculiarity, viz. that while all satellites (those of the Earth, of Jupiter, of Saturn), as well as all the principal planets, move from west to east; and with the exception of a few asteroids in orbits not much inclined towards the ecliptic, the satellites of Uranus move from *east* to west in orbits which are nearly circular, and form an angle of 78° 58′ with the ecliptic—very nearly perpendicular to it. In the case of the satellites of Uranus, as well as those of Saturn, the *arrangement* and nomenclature, according to their *distances* from the primary, are to be distinguished from the *arrangement* according to *the epoch of discovery*. According to a private communication from Sir John Herschel (November 8th, 1851), Mr. Lassell has distinctly observed on the 24th, 28th, 30th of October, and 2nd of November of the above year, two satellites of Uranus, which appear to be situated still nearer to the primary than the first satellite observed by Sir William Herschel, to which he ascribed a period of revolution of about 5 days and 21 hours, but which was not recognized. The periods of revolution of the two satellites now seen by Lassell were near to 4 and 2½ days. Of the satellites of Uranus the second and fourth were first discovered by William Herschel in 1787, then the first and fifth in 1790, and, finally, the sixth and third in 1794. During the fifty-six years which have elapsed since the last discovery of a Uranus satellite (the third), the existence of six satellites has frequently been unjustly doubted; the observations of the last twenty years have gradually proved how trustworthy the great discoverer of Slough has been in this as in all other branches of planetary astronomy. Those satellites of Uranus which have been *seen*

again up to this time are the first, second, fourth, and sixth. Perhaps it may be ventured to add the third, after the observations of Lassell on the 6th November, 1848. On account of the large opening of his reflecting telescope, and the abundance of light thus obtained, the elder Herschel considered that with the sharpness of his vision, under favourable atmospheric circumstances, a magnifying power of 157 was sufficient; his son recommends in general a power of 300 for these extremely small luminous discs (luminous points). The second and fourth satellites were seen again the earliest, the most frequently and positively by Sir John Herschel, from 1828 to 1834, in Europe and at the Cape of Good Hope, subsequently by Lamont at Munich and Lassell at Liverpool. The first satellite of Uranus was found by Lassell (September 14th to November 9th, 1847), and by Otto Struve (October 8th to December 10th, 1847). The outermost (the sixth) by Lamont (October 1st, 1837). The fifth appears never to have been seen again, and the third not satisfactorily enough.[21] The particulars here put together are not without importance, also for the reason that they tend to excite caution in not placing too much confidence in so-called negative evidence.

NEPTUNE.

The merit of having successfully conducted and announced an inverse problem of disturbance, that "of deducing from the given disturbances of a known planet the elements of an unknown one," and even of having by a bold prediction occasioned the important discovery of Neptune by Galle on the 23rd of September, 1846, belongs to the faculty of acute

[21] For the observations of Lassell at Starfield (Liverpool), and of Otto Struve, compare *Monthly Notices of the Royal Astron. Soc.* vol. viii. 1848, pp. 43–47 and 135–139; also Schum. *Astr. Nachr.* No. 623, p. 365.

reasoning and the persevering industry of Leverrier.[92] This is, as Encke expresses himself, the most brilliant of all planetary discoveries, because purely theoretical investigations have rendered possible the prediction of the existence and the place of the new planet. The celerity with which the planet was afterwards found, was itself favoured by the excellent star-chart drawn up by Bremiker for the Berlin Academy.[93]

While among the distances of the exterior planets from the Sun, that of Saturn (9·53) is nearly double as great as the distance of Jupiter (5·20), the distance of Uranus (19·18) is, however, *more* than double that of Saturn; so the distance of Neptune (30·04) is less than that which would be required for a repeated doubling of the distance by full ten times the distance of the Earth from the Sun, *i.e.* an entire third of Neptune's distance from the Sun. The *planetary boundaries* were at that time 2484 million of geographical miles from the central body. By the discovery of Neptune the landmark of our planetary knowledge has been advanced more than 892 million miles further (more than 10·8 times the distance of the Sun from the Earth). According as the disturbances are recognized which each last planet experiences, so will other planets be gradually discovered which now remain invisible by means of our telescopes on account of their remoteness.[94]

According to the most recent determinations, Neptune's *period of revolution* is 60126·7 days, or 164 years and 226 days, and his *half major axis* 30·03628. The *excentricity* of

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[92] Berhard von Lindenau, *Beitrag zur Geschichte der Neptuns-Entdeckung* in the supplementary sheet to Schum. *Astr. Nachr.* 1849. p. 17.

[93] *Astr. Nachr.* No. 580.

[94] Leverrier, *Recherches sur les mouvemens de la Planète Herschel*, 1846, in the *Connaissance des Temps pour l'an* 1849, p. 254.

his orbit, next to that of Venus the smallest, is 0·00871946; his *mass*, $\frac{1}{14446}$; his *apparent diameter*, according to Encke and Galle, 2″·70, according to Challis even 3″·07; which gives as his *density*, in comparison with the Earth, 0·230; greater, therefore, than that of Uranus 0·173.[95]

Soon after the first discovery of Neptune by Galle, a *ring* was ascribed to him by Lassell and Challis. The former employed a magnifying power of 567, and endeavoured to determine the considerable inclination of the *ring* to the ecliptic; but subsequent investigations have, as long before, in the case of Uranus, contradicted the opinion of the existence of a ring round Neptune.

I dare scarcely allude in this work to the certainly earlier labours of the distinguished and acute English geometrician, Mr. Adams, of St. John's College, Cambridge. The historical facts which refer to these labours, and to Leverrier's and Galle's happy discovery of the new planet, have been circumstantially and impartially developed from reliable sources in two works, by the Astronomer Royal, Airy, and by Bernhard Von Lindenau.[96] Intellectual endeavours, almost simultane-

[95] The very important element of the *mass* of Neptune has been gradually increased from $\frac{1}{20897}$ according to Adams, $\frac{1}{19840}$ according to Peirce, $\frac{1}{19400}$ according to Bond, and $\frac{1}{18780}$ according to Sir John Herschel, $\frac{1}{15480}$ according to Lassell, to $\frac{1}{14446}$ according to Otto and August Struve. The last result has been adopted in the text.

[96] Airy, in the *Monthly Notices of the Royal Astronomical Society*, vol. vii. no. 9 (November, 1846), pp. 121–152. Bernhard von Lindenau, *Beitrag zur Geschichte des Neptuns-Entdeckung*, pp. 1–32, and 235–238. At the instigation of Arago, Leverrier commenced, in the summer of 1845, his investigations of the theory of Uranus. The results of this investigation he laid before the Institute on the 10th of November, 1845, the 1st of June, 31st of August, and 5th of October, 1846, and *published* them at the same time; but the most extensive and important of Leverrier's labours which

ously directed to the same important end, present in their laudable competition so much the more interest, as they testify by the selection of means to the present distinguished condition of higher mathematical knowledge.

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contained the solution of the whole problem appeared in the *Connaissance des Temps pour l'an* 1849. Adams laid the first results which he had obtained for the disturbing planet before Professor Challis in September, 1845, without having them printed, and together with some alterations in October of the same year, before the Astronomer Royal, still without making them public. The latter received the final results of Adams, with fresh corrections referring to a decrease of the distance, in the commencement of September, 1846. The young Cambridge geometrician expresses himself upon the chronological succession of the investigations which were directed to one and the same object with as much modesty as self-denial: "I mention these earlier dates merely to show that my results were arrived at independently and previously to the publication of M. Leverrier, and not with any intention of interfering with his just claims to the honour of the discovery. For there is no doubt that his researches were first published to the world, and led to the actual discovery of the planet by Dr. Galle: so that the facts stated above cannot detract in the slightest degree from the credit due to M. Leverrier." Since, in the history of the discovery of Neptune, mention is frequently made of an early share which the great Königsberg astronomer took in the hope already expressed by Alexis Bouvard (the author of the tables of Uranus) in the year 1834, "of the disturbance of Uranus by a yet unknown planet," it will perhaps not be unacceptable to many readers of the *Cosmos* if I introduce here part of a letter which Bessel wrote to me on the 8th of May, 1840 (therefore two years before his conversation with Sir John Herschel, during his visit to Collingwood): "You request me to give you information as to the *planet beyond Uranus*. I could indeed refer you to friends in Königsberg who, from misunderstanding, fancy that they know more about the matter than I do myself. I chose as the subject of a public lecture delivered upon the 28th of February, 1840, the development of the connection between *astrono-*

THE SATELLITES OF NEPTUNE.

While in *exterior* planets the existence of a *ring* presents itself only in one solitary instance, and its rarity permits of the conjecture that the organ and formation of an unconnected girdle depends upon the conjunction of peculiar and difficultly

mical observations and *astronomy*. The public know no difference between the two; consequently their opinion was to be corrected. The indication of the development of astronomical knowledge from observations, naturally led to the remark that we can by no means affirm that our theory explains all the motions of the planets. Uranus afforded a proof of this. the *old* observations of which do not at all accord with elements which coincide with the later observations from 1783 to 1820. I believe that I once told you that I have worked much upon this subject, but have come to no other result than the *certainty* that the present theory, or much rather its application to the *solar system, as we are acquainted with it*, was insufficient to solve the mystery. Nevertheless, it must not on that account be considered upon my opinion to be unsolvable. We must first know accurately and completely what has been observed of Uranus. By the aid of one of my young hearers, Flemming, I have had all the observations reduced and compared, and thus the existing facts now lie before me complete. While the old observations do not agree with the theory, the more recent ones agree still less; for now the error is a whole minute, and increases annually about 7″ to 8″, so that it will soon be much greater. I was therefore of opinion that the time might come when the solution of this mystery might perhaps be found in the discovery of a new planet whose elements might be ascertained by its influences upon Uranus, and confirmed by those exerted upon Saturn. That this time has already arrived I am far from saying, but I shall *examine* now *how far* the existing facts can carry us. This is an investigation which I have pursued for so many years, and on account of which I have followed so many views, that its results especially interest me, and shall therefore be brought to an end as soon as possible. I have great confidence in

fulfilled conditions; so on the contrary the existence of satellites accompanying the *exterior* planets (Jupiter, Saturn, Uranus), is a phenomenon as universal as the former is rare. Lassell discovered with certainty[97] the first satellite of Neptune so soon as the commencement of August, 1847, in his large venty-feet reflector, with a 24 inch aperture. Lassell's discovery was confirmed by Otto Struve[98] at Pulkowa (September 11th to December 20th, 1847), and Bond,[99] the director of the observatory at Cambridge (U. S.) (September 16th, 1847). The Pulkowa observations gave: the *period of rotation* of Neptune's satellite 5d. 21h. 7m.; the inclination of its orbit to the plane of the ecliptic, 34° 7′; the *distance* from the centre of the primary, 216,000 geographical miles; the *mass*, $\frac{1}{14506}$. Three years afterwards (August 14th, 1850), Lassell discovered a second satellite, for the examination of which he employed a magnifying power of 628.[100] This last discovery has not, I believe, been confirmed by other observers.

Flemming, who will, in Dantzic, to which place he has been called, continue the same reduction of observations for Saturn and Jupiter which he has now made for Uranus. It is, in my opinion, fortunate that he has (for the present) no means of observation, and has no lectures to deliver. A time will indeed come when he must institute observations *with a definite aim;* then he should no longer want the means of carrying them out any more than he does the ability to do so."

[97] The first letter in which Lassell announced the discovery was on the 6th of August, 1847. (Schumacher, *Astr. Nachr.* No. 611, p. 165.)

[98] Otto Struve, in the *Astr. Nachr.* No. 629. August Struve, in Dorpat, calculated the orbit of the first satellite of Neptune from the observations at Pulkowa.

[99] W. C. Bond, in the *Proceedings of the American Academy of Arts and Sciences*, vol. ii. pp. 137 and 140.

[100] Schum. *Astr. Nachr.* No. 729, p. 143.

III.

THE COMETS.

The comets, which Xenocrates and Theon of Alexandria call *light-clouds*, and which according to an old Chaldean belief, Apollonius Myndius considered to "ascend periodically from great distances in long regulated orbits," though subject to the attractive force of the central body, form a peculiar and separate group in the solar regions. They are distinguished from the planets, properly so called, not merely by the eccentricity of their orbits, and what is still more important, their *intersection* of the planetary orbits; they also present a variability of figure, a change of outline, which in some instances has been observable during the space of a few hours; as, for example, in the Comet of 1744, so accurately described by Hensius, and at the last appearance of Halley's Comet in 1835. Before Encke had discovered the existence of *interior comets of short periods of revolution*, whose orbits were enclosed within those of the planets, dogmatic speculations, founded upon false analogies as to the increasing excentricity, magnitude, and decreasing density in proportion to the distance from the Sun, led to the opinion that planetary bodies of enormous volume would be discovered beyond Saturn, revolving in excentric orbits, and "forming an intermediate group between planets and comets, and indeed that the last exterior planet ought to be called a comet, since perhaps its orbit intersected that of Saturn,

the planet next to it."[1] Such an opinion of the connection of forms in the universe, analogous to the frequently misemployed doctrine of transition in organic nature, was shared by Immanuel Kant, one of the greatest minds of the eighteenth century. At two epochs, twenty-six and ninety-one years after the *Naturgeschichte des Himmels* was dedicated to the great Frederick by the Königsberg philosopher, Uranus and Neptune were discovered by William Herschel and Galle; but the orbits of both planets have a less degree of excentricity than that of Saturn; if even the latter is 0·056, so on the contrary Neptune, the outermost of all known planets, moves in an orbit whose excentricity is 0·008, nearly the same as that of Venus (0·006). In addition to this, Uranus and Neptune present none of the predicted cometary characters.

As in more recent times (since 1819), the discovery of Encke's Comet was gradually followed by those of five *interior* comets, forming as it were a peculiar group, the semi-

[1] "By means of a series of intermediate members," says Immanuel Kant, "the last planets beyond Saturn would gradually pass into comets, and so the last species would be connected with the first. The law according to which the excentricity of the planetary orbits is proportionate to the distances of the planets from the Sun, supports this conjecture. The excentricity increases with the distance, and consequently the more distant planets approach nearer to the definition of comets. The last planet and the first comet may be called that body which in its perihelion intersects the orbit of the adjoining planet, perhaps that of Saturn. Our theory of the mechanical formation of the cosmical bodies is also *clearly proved* by the magnitudes of the planetary masses which increase with the distance from the Sun."—Kant, *Naturgeschichte des Himmels* (1755), in his *Sämmtliche Werke*, Th. vi. pp. 88 and 195. At the commencement of the fifth section (p. 131), he speaks of the former *cometary nature* which Saturn was supposed to have possessed.

major axis of whose orbits for the most part resembles those of the small planets, the question was raised as to whether the group of *interior* comets may not, as is conjectured by Olbers, in his hypothesis respecting the small planets, originally have formed a single cosmical body; whether the large comet may not have been separated into several by the influence of Mars, in the same way that such a separation, as it were a bipartition, took place under the eye of the observer in the year 1846, on the occasion of the last return of the interior comet of Biela. Certain similarities in their elements have induced Professor Stephen Alexander, of the College of New Jersey, to institute investigations[2] as to the possibility of a common origin of the asteroids between Mars and Jupiter, with some or even all of the comets. The grounds of analogy which have been deduced from the nebulous envelopes of the asteroids must, according to all more recent and accurate observations, be renounced. The orbits of the small planets are not parallel to each other; that of Pallas

[2] Stephen Alexander, "On the Similarity of arrangement of the Asteroids and the Comets of short period, and the possibility of their common origin," in Gould's *Astronom. Journal*, no. 19, p. 147, and no. 20, p. 181. The author distinguishes, with Hind, (Schum. *Astr. Nachr.* No. 724), "the comets of short period, whose semi-axes are all nearly the same with those of the small planets between Mars and Jupiter; and the other class, including the comets whose mean distance or semi-axis is somewhat less than that of Uranus." He concludes the first essay with this remark: "Different facts and coincidences agree in indicating a near appulse if not an actual collision of Mars with a large comet in 1315 or 1316, that the comet was thereby broken into three parts, whose orbits (it may be presumed) received even then their present form; viz. that still presented by the Comets of 1812, 1815 and 1846, which are fragments of the dissevered comet."

certainly presents the phenomenon of an extreme inclination; but with all the want of parallelism between their own orbits, still *they do not intersect in a cometary manner* any one of the orbits of the large older, *i. e.* earlier discovered, planets. This circumstance, so extremely essential in every assumption of a primitive projectile direction and projectile velocity, appears, besides the difference in the physical constitution of the *interior* comets, and the entirely vapourless *small planets*, to render the similarity of origin of both kinds of cosmical bodies very improbable. Laplace also, in his theory of planetary genesis from rings of vapour revolving round the Sun, in which matter aggregates into spheres around a nucleus, considered it necessary to separate the comets from the planets: "*Dans l'hypothèse des zones de vapeurs et d'un noyau s'accroissant par la condensation de l'atmosphère qui l'environne, les comètes sont étrangères au système planétaire.*"[3] "According to the hypothesis of zones of vapour, and of a nucleus increasing by the condensation of the atmosphere which surrounds them, the comets are strangers to the planetary system."

We have already directed attention, in the *Delineations of Nature*,[4] to the fact that the comets at the same time possess the smallest *mass*, and occupy the largest *space*, of any bodies in the solar regions; in their number also they exceed all other planetary bodies, the theory of probabilities, applied to the data of the equable distribution of the *orbits*, the *boundaries*, the *perihelions*, and the possibility that *some remain invisible*, indicates the existence of many thousands. We except the aërolites or meteoric asteroids, as their nature is still enveloped in great obscurity. Among the

[3] Laplace, *Expos. du Syst. du Monde* (ed. 1824), p. 414.

[4] On Comets: in the *Delineation of Nature*, see *Cosmos*, vol. i. pp. 84—97.

comets, those must be distinguished whose orbits have been calculated by astronomers; and such of which there are only incomplete observations, or mere indications recorded. As, according to Galle's last accurate enumeration, 178 had been calculated up to the year 1847, so it may be admissible to adopt as the total number, with those which have been merely indicated, the assumption of six or seven hundred observed comets. When the Comet of 1682, predicted by Halley, appeared again in 1759, it was considered very remarkable that three comets should be visible in the same year. At the present time, the investigation of the heavens is carried on simultaneously at several parts of the globe, and with such energy, that in each of the years 1819, 1825, and 1840, four were discovered and calculated, in 1826 five, and in 1846 even eight.

Of comets visible with the naked eye, more have been observed recently than during the latter part of the previous century; but among them those which have a great brilliancy in the head and tail, still remain, on account of their unfrequency, remarkable phenomena. It will not be without interest to enumerate how many comets, visible in Europe to the naked eye, have appeared during the last centuries. The epoch in which they were most numerous was the sixteenth century, during which 23 such comets were seen. The seventeenth numbered 12, and of these only 2 during its first half. In the eighteenth century only 8 appeared, but 9 during the first fifty years of the nineteenth century. Among these, the most beautiful were those of 1807, 1811, 1819, 1835, and 1843. In earlier ages, thirty or forty years have frequently passed without such a spectacle presenting itself in a single instance. In the years, however, during which comets seldom appear, there may be a number of large comets whose

[5] In the seven half centuries from 1500 to 1850, altogether 52 comets have appeared which were *visible to the naked eye;*

perihelia are situated beyond the orbits of Jupiter and Saturn. Of the telescopic comets, there are at the present time upon an average at least 2 or 3 discovered annually. In three *suc-*

in separate succession during seven equal periods, 13, 10, 2, 10, 4, 4, and 9. The following are the individual years:—

1500—1550 13 Com.	1550—1600 10 Com.
1600—1650 1607 1618 — 2 Com.	1650 – 1700 1652 1664 1665 1668 1672 1680 1682 1686 1689 1696 — 10 Com.
1700—1750 1702 1744 1784 (2) — 4 Com.	1750—1800 1759 1766 1769 1781 — 4 Com.

1800—1850
1807
1811
1819
1823
1830
1835
1843
1845
1847

9 Com.

cessive months (1840) Galle discovered 3 new comets; from 1764 to 1798, Messier discovered 12; from 1801 to 1827, Pons discovered 27. Thus Kepler's expression as to the number of comets in the universe appears to hold good: *ut pisces in oceano.*

Of not less importance is the careful catalogue of comets which have appeared in China, and which Edward Biot has made known from the collection of Ma-tuan-lin. It reaches back beyond the foundation of the Ionic school of Thales and the Lydian Alyattes; and comprises, in two sections, the place of the comets from 613 years before our own era until 1222 years afterwards, and then from 1222 to 1614, the period in which the dynasty of Ming ruled. I repeat here (see *Cosmos*, vol. i. p. 84), that while from the middle of the third to the end of the fourteenth century it was necessary to calculate comets exclusively from the Chinese observations, the calculation of Halley's Comet, on its appearance in the year 1456, was the first calculation which was made from altogether European observations, those of Regiomontanus. These latter were again followed by the very accurate observations of Apianus at Ingoldstadt, upon the occasion of the reappearance of Halley's Comet in August of the year 1531. In the interval (May, 1500), appeared a magnificently brilliant comet,* rendered famous by African and Brazilian travels

Of the 28 Comets visible to the naked eye which are here enumerated in the sixteenth century (the epoch of Apianus, Girolamo Fracastoro, Landgravine William IV. of Hesse, Mästlin and Tycho) 10 were described by Pingré, namely, those of 1500, 1505, 1506, 1512, 1514, 1516, 1518, 1521, 1522, and 1530; further the Comets of 1531, 1532, 1533, 1556, 1558, 1569, 1577, 1580, 1582, 1585, 1590, 1593, and 1596.

* This is the "evil-disposed" comet to which was ascribed the death of the celebrated Portuguese discoverer Bartho-

of discovery, which was called in Italy *Signor Astone*, the *great Asta*. Laugier[7] has detected, by similarity of the elements in the Chinese observations, a seventh appearance of Halley's Comet (that of 1378): as well as that the third comet of 1840, discovered by Galle,[8] on the 6th of March, appears to be identical with that of 1097. The Mexicans also connected events in their records with comets and other observations of the heavens. The Comet of 1490, which I discovered in the Mexican manuscript of St. Tellier, and of which an engaving is inserted in my *Monumens des Peuples indigènes de l'Amérique*, I have found, singularly enough, to be mentioned as having been observed in December of that year only in the Chinese comet-register.[9] The Mexicans had inserted it in their register twenty-eight years before the first appearance of Cortes upon the coasts of Vera Cruz (Chalchinhcuecan).

I have in the Delineations of Nature (*Cosmos*, vol. i. p. 86) treated fully of the configuration, alterations of form, light, and colour of comets, the emanations from their heads

lomæus Diaz, by shipwreck, as he was sailing to the Cape of Good Hope; Humboldt, *Examen Crit. de l'Hist. de la Géogr.* tom. i. p. 296, and tom. v. p. 80. (Sousa, *Asia Portug.* tom. i. p. 1, cap. v. p. 45.)

[7] Laugier, in the *Connaissance des Temps pour l'an* 1846, p. 99. Compare also Edward Biot, *Recherches sur les Anciennes Apparitions Chinoises de la Comète de Halley antérieures à l'année* 1378, *op. cit.* pp. 70–84.

[8] Upon the comet discovered by Galle in March, 1840, see Schumacher, *Astr. Nachr.* Bd. xviii. p. 188.

[9] See my *Vues des Cordillères* (ed. in folio), pl. lv. fig. 8, pp. 281, 282. The Mexicans had also a very correct view of the cause of a solar eclipse. The same Mexican manuscript, written at least a quarter of a century before the arrival of the Spaniards, represents the Sun as almost entirely covered by the Moon's disc, and with stars visible at the same time.

which bent backwards,[10] form the tails, from the observations of Hensius (1744), Bessel, Struve, and Sir John Herschel. Besides the magnificent Comet of 1843,[11] which could be seen by Bowring in Chihuahua (N.W. America) as a small white cloud from nine o'clock in the morning until sunset, and by Amici, in Parma, at full noon, 1° 23′ eastward of the Sun,[12]

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[10] This formation of *the tail* at the *anterior part* of the comet's head, which has occupied Bessel's attention so much, was the opinion of Newton and Winthrop (compare Newton's *Principia*, p. 511, and *Philos. Transact.* vol. lvii. for the year 1767, p. 140, fig. 5). Newton considered that the tail was developed most considerably and longer near the Sun, because the *cosmical ether* (which we call with Encke the *resisting medium*) was the *densest* there, and the *particulæ caudæ*, strongly heated and supported by the ether, ascended more easily. Winthrop considered that the principal effect did not take place until some time after the perihelion passage, because, according to the law established by Newton (*Principia*, pp. 424 and 466), the maxima are universally retarded (in periodical changes of heat as well as in ocean tides).

[11] Arago, in the *Annuaire pour* 1844, p. 395. The observation was made by the younger Amici.

[12] With regard to the Comet of 1843, which appeared with unexampled splendour in Northern Europe during the month of March, near Orion, and approached nearer to the Sun than any hitherto observed and calculated comet, all the details are collected in Sir John Herschel's *Outlines of Astronomy*, § 589–597; and in Peirce, *American Almanac for* 1844, p. 42. On account of physiognomical resemblances whose uncertainty was already shown by Seneca (*Nat. Quæst.* lib. vii. caps. xi. and xvii.), it was at first considered to be identical with the comets of 1668 and 1689 (*Cosmos*, vol. i. p. 128, note; Galle, in Olbers' *Cometenbahnen*, nos. 42 and 50). Boguslawski (Schum. *Astr. Nachr.* No. 545, p. 272) believes, on the contrary, that its previous appearances were, with a revolution of 147 years, those of 1695, 1548, and 1401; he even calls it the *Comet of Aristotle*, "because he traces it back to the year 371 before our era, and together with the talented Hellenist Thiersch of Munich, considers it to be a comet which is mentioned in

the first comet of the year 1847, discovered by Hind near Capella, has very recently been visible at London, near the Sun, on the day of its perihelion.

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the *Meteorologicis* of Aristotle, book i. cap. vi." But I would call to mind that the name *Comet of Aristotle* is vague and indefinite. If that one is meant which Aristotle states to have disappeared in Orion, and which he connects with the earthquake in Achaia, it must not be forgotten that this comet is stated by Callisthenes to have appeared *before*, by Diodorus *after*, and by Aristotle *at the time* of the earthquake. The sixth and eighth chapters of the *Meteorology* treat of four comets whose epochs of appearance are characterized by the Archons at Athens, and by unfortunate events. In this place those are mentioned in order: the *western* comet which appeared on the occasion of the great earthquake at Achaia, accompanied with floods (cap. vii. 8): then the comet which appeared during the time of the Archon Eucles, the son of Molon; afterwards (cap. vi. 10), the Stagirite comes again to the *western* comet, that of the great earthquake, and at the same time calls the Archon Asteus—a name which incorrect readings have changed into Aristæus, and which was on that account erroneously considered by Pingré, in his *Cométographie* to signify one and the same person as Aristhenes or Alcisthenes. The brilliancy of this comet of Asteus diffused itself over the third part of the sky; the tail which was called its way (ὁδός) was also 60° in length. It extended nearly as far as Orion, where it gradually disappeared. In cap. vii. 9, the comet is mentioned which appeared simultaneously with the famous fall of aërolites near Ægos Potamos (*Cosmos*, vol. i. p. 103), and which can scarcely be a confusion with the *aërolite-cloud* described by Damachos, which shone for 70 days, and poured forth falling stars. Finally, Aristotle mentions (cap. vii. 10), a comet which appeared at the time of the Archon Nicomachus, to which was ascribed a storm near Corinth. These four appearances of comets occurred during the long period of 32 Olympiads: viz. the fall of aërolites, according to the *Parian Chronicle*, Ol. 78, 1. (468 B. C.), under the Archon Theagenides; the great comet of Asteus which appeared

For the explanation of what has been said above of the remark of Chinese astronomers on the occasion of their observation of the Comet of March, 837, in the dynasty of

at the time of the earthquake at Achaia, and disappeared in the constellation of Orion, in *Ol.* 101, 4 (373 B.C.): Eucles, the son of Molon, erroneously called Euclides Diodorus (xii. 53,) in *Ol.* 88, 2 (427 B.C.), as is also confirmed by the commentary of Johannes Philoponus; the comet of Nicomachus in *Ol.* 109, 4 (341 B.C.). The date assigned by Pliny for the *jubæ effigies mutata in hastam*, is *Ol.* 108 (*Plinius*, ii. 25). Seneca also agrees in connecting the comet of Asteus (*Ol.* 101, 4) immediately with the earthquake in Achaia, as he mentions the downfall of Bura and Helice, which towns Aristotle does not expressly mention, in the following manner: "Effigiem ignis longi fuisse, Callisthenes tradit, antequam Burin et Helicen mare absconderet. Aristoteles ait, non trabem illam, sed cometam fuisse." "Callisthenes affirms that the fiery shape appeared long before the sea overwhelmed Buris and Helice. Aristotle says that this was not a meteor, but a comet." (Seneca, *Nat. Quæst.* vii. 5). Strabo (viii. p. 384, *Cas.*) places the downfall of these two frequently mentioned towns two years before the battle of Leuctra, whence again results the date, *Ol.* 101, 4. Finally, after Diodorus Siculus had more fully described this event as having occurred under the Archon Asteus (xv. 48, 49), he places the brilliant comet which *threw shadows* (xv. 50) under the Archon Alcisthenes a year later, *Ol.* 102, 1 (372, A.C.), and as a prediction of the decline of the Lacedæmonian rule; but the later Diodorus had the habit of transferring an event from one year to another: and the oldest and most reliable witnesses, Aristotle and the Parian Chronicle, speak in favour of the epoch of Asteus *before* that of Alcisthenes. Now since the assumption of a period of revolution for the beautiful Comet of 1843 of 147¾ years, leads Boguslawski to assign to its appearances the dates 1695, 1548, 1401, and 1106 up to the year 371 before our era, the comet of the *earthquake of Achaia* corresponds with it, according to Aristotle, within two—according to Diodorus to within one year: which, if we could know anything of the similarity of the orbit, is, when taking into consideration the probable disturbances,

Thang, I insert here a translation from Ma-tuan-lin' of the verbal statement of the law of direction of the tail. It is said there: "In general the tail of a comet which is situated

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during a period of 1214 years, certainly a very small error. When Pingré, in the *Cométographie* (1783, tom. i. pp. 259–262), relying upon Diodorus and the Archon Alcisthenes instead of Asteus, places the comet in question in Orion, in *Ol.* 102, and still in the commencement of July, 371 before Christ, instead of 372; the reason perhaps lies in the circumstance that, like some other astronomers, he characterises the first year before the Christian era, as *anno* 0. It is to be observed, in conclusion, that Sir John Herschel assumes for the Comet of 1843, seen in full daylight near the Sun, an entirely different period of revolution, one of 175 years; which leads to the years 1668, 1493, and 1318, as the dates of its previous appearances. (Compare *Outlines*, pp. 208–372, with Galle, in Olbers' *Cometenbahnen*, p. 208; and *Cosmos*, vol. i. p. 126.) Other combinations by Peirce and Clausen lead to periods of revolution of even $21\frac{4}{5}$ or $7\frac{1}{5}$ years:—a sufficient proof how hazardous it is to trace back the Comet of 1843 to the Archonship of Asteus. The mention of a comet under the Archonship of Nicomachus, in the *Meteorol.* lib. i. cap. vii. 10, has at least the advantage of showing us that this work was written when Aristotle was at least 44 years of age. It has always appeared to me remarkable that the great man, as he was already 14 years old at the time of the earthquake at Achaia, and of the appearance in Orion of the great comet with a tail 60° in length, should speak with so little animation of so brilliant an object, and content himself with enumerating it among the other comets "which had appeared in his time." The astonishment increases when in the same chapter the statement is found that he had seen with his own eyes something misty, even a feeble haze (κόμη) round a fixed star in the hip-bone of the Dog (perhaps Procyon in the small Dog.) (*Meteorol.* i. 6, 9.) Aristotle also speaks (i. 6, 11) of his observation of the occultation of a star in Gemini by the disc of Jupiter. With regard to the vaporous or nebulous envelope of Procyon (?), it recalls to my mind a phenomenon of which frequent mention is made in the old Mexican annals according to the *Codex Tellerianus*. "This year," it is said there, "*Citlal-*

eastwards from the Sun is directed towards the east, calculating from the nucleus; but if the comet appears to the west of the Sun, the tail turns towards the west."[13] Fracastoro and Apianus say, still more correctly, "that a line produced through the head of a comet in the direction of the axis of the tail meets the Sun." The words of Seneca are also characteristic: "The tails of comets fly from the Sun's rays." (*Nat. Quæst.* vii. 20.) While among the yet known planets and comets the periods of rotation dependent upon the half-major axis, the *shortest* and the *longest* of the planets are in the proportion of 1 : 683, the proportion in the case of the comets is as 1 : 2670. Mercury (87d·97.) is here compared with Neptune (60,126d·7.), and the Comet of Encke (3·3 years) with the Comet of 1680 (8814 years) observed by Gottfried Kirch at Coburg, Newton, and Halley. The distance of the fixed star nearest to our solar system (*a* Centauri) from the aphelion (point of greatest distance from the Sun) of the last-named comet is determined by Encke in an excellent treatise. The small velocity of its motion (ten feet in a second) in this outermost part of its orbit, the *greatest proximity* which the Comet of Lexell and Burckhardt (1770) has attained to the *earth* (six times the distance of the Moon), and the Comet of 1680 (and still more that of 1843) to the Sun, I have already treated of in *Cosmos*, vol. i. p. 95, and vol. iv. pp. 351—353. The second comet of the year 1819, which appeared, in Europe, suddenly to break forth from out of the Sun's rays in considerable magnitude, passed, according

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choloa smoked again;" this is the name of the planet Venus, also called Tlazoteotl in the Aztec language (see my *Vues des Cordillères*, tom. ii. p. 303): this is probably, in the Grecian as well as the Mexican sky, a phenomenon of atmospheric refraction—the appearance of small haloes.

[13] Edward Biot, in the *Comptes rendus*, tom. xvi. 1843, p. 751.

to the calculation of its elements, *across the Sun's disc* on the 26th of June;[14] unfortunately its passage was not observed. This must also have been the case with the Comet of 1823, which, besides the ordinary tail turned from the Sun, had also another turned directly towards it. If the tails of both comets had a considerable length, vaporous parts of them must have mixed with our atmosphere, as certainly often happens. The question has been raised as to whether the wonderful mists of 1783 and 1831, which *covered a great part of the Continent, were consequences of such an admixture?*[15]

While the quantity of radient heat received by the Comets of 1680 and 1843 in such close proximity to the Sun has been compared to the focal temperature of a 32-inch burning mirror;[16] a highly-deserving[17] astronomical friend of mine

[14] Galle, in the Supplement to Olbers' *Cometenbahnen*, p. 221, no. 130. (With respect to the probable passage of the two-tailed comet of 1823, see *Edinb. Rev.* 1848, no. 175, p. 193.) The treatise shortly before quoted in the text, containing the true elements of the Comet of 1680, contradicts Halley's fantastic idea, according to which, with a presumed period of 575 years, it had appeared at all the great epochs of the human race: at the time of the Deluge according to Hebrew traditions, in the age of Ogyges according to Greek traditions, at the Trojan war, on the destruction of Nineveh, on the death of Julius Cæsar, &c. The period of revolution resulting from Encke's calculation is 8814 years. The least distance from the surface of the Sun was, on the 17th of December, 1680, only 128,000 geographical miles; consequently 80,000 less than the distance of the Earth from the Moon. The aphelion is 853·3 times the distance of the Earth from the Sun, and the proportion of the smallest to the greatest distance from the Sun is as 1 : 140000.

[15] Arago, in the *Annuaire pour* 1832, pp. 236–255.

[16] Sir John Herschel, *Outlines*, §. 592.

[17] Bernhard von Lindenau, in Schumacher, *Astr. Nachr.* no. 698, p. 25.

maintains that "all comets which are without a solid nucleus (on account of their extremely small density), have no solar heat, only the temperature of cosmical space."[18] If we take into consideration the numerous and striking analogies of the phenomena which, according to Melloni and Forbes, luminous and non-luminous sources of heat present, it appears difficult, in the present state of our physical reasoning, not to assume that processes go on in the Sun itself which simultaneously produce radiant light and radiant heat by vibrations of the ether (waves of different lengths). The darkening of the Moon by a comet, stated to have taken place in the year 1454, which the Jesuit Pontanus, the first translator of the Byzantine author, George Phranza, believed that he had discovered in a monkish manuscript, has long been mentioned in many astronomical works. This statement of the passage of a comet between the Earth and Moon in 1454 is quite as erroneous as that asserted by Lichtenberg of the Comet of 1770. The Chronicon of Phranza first appeared complete at Vienna in 1796, and it is said there expressly, that in the year of the world 6962, while an eclipse of the Moon took place, *a comet like a mist appeared and came near to the Moon quite in the ordinary manner, according to the order and circular orbits of the heavenly luminaries.* The year of the world (=1450) is incorrect, as Phranza says distinctly the eclipse of the Moon and the appearance of the comet were seen *after* the taking of Constantinople (May the 19th, 1453), and an eclipse of the Moon actually happened upon the 12th of May, 1454. (See Jacobs, in Zach's *Monatl. Corresp.* bd. xxiii. 1811, pp. 196–202.)

The relation of Lexell's Comet to the satellites of Jupiter, and the perturbation which it suffers from them without influencing their periods of revolution (*Cosmos*, vol. i. p. 96), have

[18] *Cosmos*, vol. iii. pp. 42 and 45.

been more accurately investigated by Leverrier. Messier discovered this remarkable comet as a feeble nebulous spot in Sagittarius upon the 14th of June, 1770; but eight days after, its nucleus shone as brightly as a star of the 2nd magnitude. Before the perihelion passage, no tail was visible; afterwards it developed itself by slight emanations scarcely one degree in length. Lexell found for his comet an elliptic orbit, and the period of rotation of 5·585 years, which Burckhardt confirmed in his excellent prize essay. According to Clausen it had approached the Earth upon the 1st of July, 1770, to a distance of 363 times the Earth's radius (1,244,000 geographical miles, or six times the Moon's distance). That the comet was not seen before March, 1776, and not later than October, 1781, according to Lexell's previous conjecture, is analytically demonstrated by Laplace, in the fourth volume of the *Mécanique Céleste*, from the perturbations occasioned by the Jovial system on the occasion of the approximations in the years 1767 and 1779. Leverrier finds that according to one hypothesis respecting the cometary orbits, this comet passed through orbits of the satellites in 1779; according to another, that it remained at a considerable distance without the fourth satellite.[19]

The molecular conditions of the head or nucleus, so seldom possessing a definite outline, as well as the tail of the comets, is rendered so much the more mysterious from the fact that it causes no refraction, and, as was proved by Arago's important discovery (*Cosmos*, vol. i. p. 90, and note), that the cometary light contains a portion of *polarized* light, and consequently reflected sun-light. Although the smallest stars are seen in undiminished brilliancy through the vaporous emanations of the tail, and even through the centre of the nucleus itself, or

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[19] Leverrier, in the *Comptes Rendus*, tom. xix. 1844, 982–993.

at least in very great proximity to the centre (per centrum non aliter quam per nubem ulteriora cernatur: Seneca, *Nat. Quæst.* vii. 18); so, on the contrary, the *analysis* of the cometary light in Arago's experiments, during which I was present, shows that the vaporous envelopes are capable[20] of reflecting light notwithstanding their extremely slight density, and that these bodies have "an *imperfect* transparency,[21] since light does not pass through them unimpeded." In this group of vaporous bodies, the solitary instances of great luminous intensity, as in the Comet of 1843, or the star-like shining of a nucleus, excite so much the more astonishment when it is assumed that their light proceeds solely from a reflection of the solar rays. Is there not, however, in addition to this, a peculiar light-producing process going on in the comets?

The brush-like membered tails emanating from the comets, and consisting of vapoury matter of millions of miles in length, diffuse themselves in space; and form, perhaps, either the *resisting medium*[22] itself, which gradually contracts the orbit of Encke's Comet, or they mix with the old cosmical matter which has not aggregated into spheres, or condensed into the rings, and which appears to us as the zodiacal light. We see, as it were, before our eyes, material particles disappear, and can scarcely conjecture where they again collect. However probable may be the *condensation*, in the neighbourhood of the central body of our system, of a gaseous fluid filling space, still in the case of the comets whose nuclei, according to Valz, *diminish* in the perihelion, this fluid con-

[20] Newton considered that the most brilliant comets shone only with reflected sun-light. "Splendent cometæ," says he, "luce Solis a se reflexa." (*Princ. Mathem.* ed. Le Seur et Jaquier, 1760, tom. iii. p. 577.

[21] Bessel, in *Schum. Jahrbuch for* 1837, p. 169.

[22] *Cosmos*, vol. i. p. 92, and vol. iii. p. 47.

densed there, can scarcely be looked upon as pressing upon a vesicular vapoury envelope.[23] Although in the streamers of the comets the outlines of the reflecting portion of the vapoury envelope is generally very indefinite, the circumstance that in some individuals (for example, Halley's Comet at the 2nd of January, 1836, at the Cape of Good Hope), a sharpness of outline has been observed on the anterior parabolic part of the body, such as our masses of clouds seldom present, is so much the more striking and instructive as to the molecular condition of these bodies. The celebrated observer at the Cape compared the unusual appearance, testifying to the intensity of the mutual attraction of the particles, with that of an alabaster vessel strongly illuminated in the interior.[24]

Since the appearance of the astronomical part of my *Delineation of Nature*, the cometary world has presented a phenomenon whose mere possibility could scarcely have been suspected beforehand. Biela's Comet, an *interior* one of

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[23] Valz, *Essai sur la détermination de la densité de l'ether dans l'espace planétaire*, 1830, p. 2; and *Cosmos*, vol. i. p. 91. The so-carefully observing and always unprejudiced Hevelius had also directed attention to the increase in the size of the cometary nuclei, with increased distance from the Sun. (Pingré, *Cométographie*, tom. ii. p. 193.) The determinations of the diameter of Encke's Comet in the perihelion is very difficult, if accuracy is desired. The comet is a nebulous mass, in which the centre, or one point of it, is the brightest, even prominently bright. From this point, which however presents no appearance of a disc, and cannot be called a *comet-head*, the light decreases very rapidly all around, and at the same time the vapour elongates towards one disc, so that this elongation appears as a tail. The measurements, therefore, refer to this mass of vapour, whose circumference, without having really definite boundaries, decreases in perihelion.

[24] Sir John Herschel, *Results of Astronomical Observations at the Cape of Good Hope*, 1847, § 366, pl. xv. and xvi.

short period, 6⅝ years in its revolution, has separated into two comets of similar figure though unequal dimensions, both having a head and tail. So long as they could be observed, they did not unite again, and proceeded on their course separately, almost parallel with each other. Hind had, on the 19th of December, 1845, already remarked a kind of protuberance towards the north; but on the 21st there was, according to Encke's observation in Berlin, still no signs of a separation visible. The subsequent separation was first detected in North America on the 29th of December, 1845; in Europe, not until the middle and end of January, 1846. The new smaller comet proceeded towards the north. The distance of the two was at first 3′, afterwards (February 20th), according to Otto Struve's interesting drawing, 6′.[25] The luminous intensity varied in such a manner that the gradually increasing secondary comet for some time exceeded the principal comet in brightness. The nebulous envelopes which surrounded each of the nuclei had no definite outlines: that of the larger comet indeed showed a less luminous protuberance towards S.S.W.; but the space between the two comets was seen at Pulkowa quite free from nebulous matter.[26] A few days later, Lieutenant Maury in Washington remarked, with a nine-inch Munich refractor, rays which proceeded from the larger older comet to the smaller new one, so that a kind of bridge-like connection was

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[25] The subsequent (5th of March) increase of distance seen to the extent of 9° 19′ was, as Plantamour has shown, merely apparent and dependent upon the approximation to the Earth. Both parts of the *double comet* remained at the same distance from each other from February until the 10th of March.

[26] "Le 19 Février, 1846, on aperçoit le fond noir du ciel qui sépare les deux comètes."—Otto Struve, in the *Bulletin physico-mathématique de l'Acad. des Sciences de St. Pétersbourg*, tom. vi. no. 4.

produced for some time. On the 24th of March, the smaller comet was scarcely perceptible, on account of the decreasing luminous intensity. The larger one only was seen up to the 16th or 20th of April, when this also disappeared. I have described the wonderful phenomenon in detail,[27] so far as it could be observed. Unfortunately, the actual separation and the immediately previous condition of the older comet escaped observation. Did the separated comet become invisible only on account of distance and feeble luminosity, or did it resolve itself? Will it be again detected as an *attendant*, and will the Comet of Biela present similar anomalies at other re-appearances?

The formation of a *new* planetary body by *separation* naturally excites the question, whether, in the innumerable comets revolving round the Sun, several have not originated by a similar process, or do not daily originate so? whether they may not acquire different orbits by retardation, *i. e.* unequal velocity of revolution, and the unequal influence of perturbations? In a treatise already alluded to, Stephen Alexander has attempted to explain the *genesis* of all the *interior comets* by the assumption of such an hypothesis, certainly but inadequately founded. In antiquity also similar occurrences appear to have been observed, but not sufficiently described. Seneca states, upon the authority, as he himself says, of an unreliable witness, that the comet which was considered to have caused the destruction of the two towns of Helice and Bura separated into two parts. He adds ironically, why has no one seen two comets unite to form one?[28] The Chinese astro-

[27] Compare *Outlines*, § 580–583; Galle, in Olbers' *Cometenbahnen*, p. 232.

[28] "Ephorus non religiosissimæ fidei, sæpe decipitur, sæpe decipit. Sicut hic Cometem, qui omnium mortalium oculis custoditus est, quia ingentis rei traxit eventus, cum Helicen

nomers speak of "three dome-formed comets," which appeared in the year 896, and pursued their course together.[29]

Among the great number of calculated comets, there are up to the present time eight known, whose period of revolution is shorter than that of Neptune. Of these eight, *six* are *interior comets*, *i. e.* such whose *aphelia* are within the orbit of Neptune, viz. the comets of Encke (aphelion, 4·09) of De Vico (5·02), Brorsen (5·64), Faye (5·93), Biela (6·19), and D'Arrest (6·44). If the distance of the Earth from the Sun is taken as = 1, the orbits of all these six *interior comets* have aphelia which are situated between Hygiea (3·15), and a limit which is nearly 1¼ the Earth's distance from the Sun beyond Jupiter. The two other comets, likewise of a shorter period of revolution than Neptune, are the 74-year *Comet of Olbers*, and the 76-year *Comet of Halley*. Up to the year 1819, when Encke first discovered the existence of an interior comet, these two latter ones were those of the shortest period among the then-calculated comets. Olbers' Comet of 1815, and Halley's Comet are, since the discovery of Neptune, situated in their aphelia only 4, and 5⅗ times the Earth's distance from the Sun—beyond the limits which would allow of their being considered interior comets. Although the term *interior* comet may suffer alteration from the discovery of *Trans-neptunian* planets since the boundary which determines whether a comet is to be called an interior one is changeable,

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et Burin ortu suo merserit, ait illum discessisse in duas stellas: quod præter illum nemo tradidit. Quis enim posset observare illud momentum, quo Cometes solutus et in duas partes redactus est? Quomodem autem, si est qui viderit Cometem in duas dirimi, nemo vidit fieri ex duabus?"—Seneca. *Nat. Quæst.* lib. vii. cap. 16.

[29] Edward Biot, *Recherches sur les Comètes de la collection de Ma-tuan-lin*, in the *Comptes rendus*, tom. xx. 1845, p. 334.

still this term is preferable to that of *comets of short period*, from the fact that it is in each epoch of our knowledge dependent upon something definite. The six *interior* comets now accurately calculated, certainly vary in their periods of revolution only from 3·3 to 7·4 years; but if the return of the comet discovered by Peters at Naples, upon the 26th of June, 1846 (the 6th comet of the year 1846 with a half-major axis of 6·32), after a period of 16 years, should be confirmed,[30] it may be foreseen that intermediate members, in reference to the duration of the period of revolution, will gradually be discovered between the Comets of Faye and Olbers. Then it would be difficult in future to fix a limit for the *shortness* of the *period*. Here follows the table in which Dr. Galle has arranged the elements of the six *interior* comets.

[30] Galle, in Olbers' *Methode der Cometenbahnen*, p. 232, No. 174. The comets of Colla and Bremiker of the years 1845 and 1840, present elliptical orbits with *proportionately* not very short periods of revolution. (I allude to the 3065 and 8800 years of the Comets of 1811 and 1680). They appear to have periods of revolution of only 249 and 344 years. (See Galle, *op. cit.* pp. 229 and 231.)

The Elements of the Six Interior Comets which are more accurately calculated.

	Encke.	De Vico.	Brorsen.	D'Arrest.	Biela.	Faye.
	1848. Nov. 26.	1844. Sept. 2.	1846. Feb. 25.	1851. July 8.	1846. Feb. 10.	1843. Oct. 17.
Date of perihelion passage in mean Paris time	2h 55′ 56″	11h 33′ 57″	9h 8′ 1″	16h 57′ 23″	23h 51′ 36″	3h 42′ 16″
Longitude of the perihelion	157° 47′ 8″	342° 30′ 55″	116° 28′ 15″	322° 59′ 46″	109° 2′ 20″	49° 34′ 19″
Longitude of the ascending node	334 22 12	63 49 17	102 40 58	148 27 20	245 54 39	209 29 19
Inclination towards the plane of the ecliptic	13 8 36	2 54 50	30 55 53	13 56 12	12 34 53	11 22 31
Half major axis	2·214814	3·102800	3·146494	3·461846	3·524522	3·811790
Perihelion distance	0·337032	1·186401	0·650103	1·173976	0·856448	1·692579
Aphelion distance	4·092595	5·019198	5·642884	5·749717	6·192596	5·931001
Excentricity	0·847828	0·617635	0·793388	0 660881	0·757003	0·555962
Period of revolution in days	1204	1996	2039	2353	2417	2718
Period of revolution in years	3·30	5·47	5·58	6·44	6·62	7·44
Calculated by	Encke, Astr. Nachr. xxvii. p. 113.	Brünnow, gekrönte Priestschrift, Amst. 1849.	Brünnow, Astr. Nachr. xxix. p. 377.	D'Arrest, Astr. Nachr. xxxiii. p. 125.	Plantamour, Astr. Nachr. xxv. p. 117.	Leverrier, Astr. Nachr. xxiii. p. 196.

From the summary here given, it follows that since the discovery of Encke's Comet[31] as an *interior* one in the year 1819, up to the discovery of the interior comet of D'Arrest, scarcely

[31] The short period of revolution of 1204 days was discovered by Encke on the reappearance of his comet in the year 1819. See the first calculated elliptical orbits in the *Berliner. Astron. Jahrbuch*, for 1822, p. 193, and for the constants of the *resisting medium* assumed to explain the accelerated revolution. Encke's *Vierte Abhandlburg* in the *Schriften der Berl. Akademie* for the year 1844. (Compare Arago, in the *Annuaire* for 1832, p. 181: in the *Lettre à M. Alexandre de Humboldt*, 1840, p. 12; and Galle, in Olbers' *Cometenbahnen*, p. 221.) As belonging to the history of *Encke's Comet*, it must here be called to mind that so far as our knowledge of the observations extends, it was first seen upon two days by Méchain on the 17th of January, 1786: then by Miss Carolina Herschel from the 7th to the 27th of November, 1795; afterwards by Bouvard, Pons, and Huth, from the 20th of October to the 19th of November, 1805; finally, as the tenth reappearance since Méchain's discovery in the year 1786, by Pons from the 25th of November, 1818, to the 12th of January, 1819. The *first* reappearance *calculated beforehand* by Encke, was observed by Rümker at Paramatta. (Galle, *op. cit.* pp. 215, 217, 221, and 222.) Biela's interior comet, or as it is also called, Biela's and Gambart's, was first seen by Montaigne on the 8th of March, 1772; then by Pons on the 10th of November, 1805; afterwards on the 27th of February, 1826, at Josephstadt in Bohemia, by Von Biela; and on the 9th of March by Gambart, at Marseilles. The earliest rediscoverer of the comet of 1772 is undoubtedly Biela, and not Gambart; but on the other hand, he calculated the elliptical elements of its orbit earlier than Biela, and nearly at the same time as Clausen. (Arago, in the *Annuaire* of 1832, p. 184; and in the *Comptes Rendus*, tom. iii. 1836, p. 415.) The *first* re-appearance of Biela's Comet, *calculated beforehand*, was observed by Henderson, at the Cape of Good Hope, in October and December, 1832. The already mentioned wonderful doubling of Biela's Comet by separation, took place at its 11th reappearance since 1772, at the end of the year 1845. (See Galle, by Olbers, pp. 214, 218, 224, 227, and 232.)

32 years have elapsed. Yvon Villarceau has also given elliptic elements for the last-named in Schumacher's *Astron. Nachr.* no. 773, and has at the same time with Valz put forward some conjectures as to its identity with the Comet of 1678, observed by La Hire, and calculated by Douwes. Two other comets, apparently of from 5 to 6 *year periods* of revolution, are the 3rd of 1819, discovered by Pons, and calculated by Encke; and the 4th of 1819, discovered by Blanpain, and according to Clausen identical with the 1st of 1743. But neither of these can be classed with those which, from longer and more accurate observations, present a greater certainty and completeness of their elements.

The inclination of the orbits of the *interior* comets to the plane of the ecliptic is, upon the whole, small, between 3° and 13°; that of Brorsen's Comet alone is very considerable, and reaches 31°. All the hitherto discovered *interior* comets have, like the principal and secondary planets of the entire solar system, a *direct* motion (from west to east, proceeding in their orbits). Sir John Herschel has directed attention to the great rarity of *retrograde* motion of comets *having a slight inclination to the plane of the ecliptic.*[32] This opposite direction of motion which occurs only with a certain class of planetary bodies, is of great importance in reference to the very universally prevailing opinion as to the formation of the planetary bodies belonging to one system, and as to the primitive, impulsive, and projectile force. It shows us the *cometary world*, although subject even at the remotest distances to the attraction of the central body, in greater individuality and independence. Such a mode of viewing the subject has led to the idea of considering the comets as older[33] than the planets—as it were

[32] *Outlines*, § 601.

[33] Laplace, *Expos. du Système du Monde*, pp. 396 and 414. The special view of Laplace as to the comets being "wandering nebulæ," (petites nébuleuses errantes de systèmes en système, solaires,) "stands in opposition to the progress which has been

primitive forms of the loosely aggregating matter in space. Under these presuppositions it becomes a question whether, notwithstanding the enormous distance of the nearest fixed stars, whose parallax we know from the aphelion of the Comet of 1680, some of the comets which appear in the heavens may not be merely *wanderers through* our solar system, moving from one Sun to another?

Next in order to the group of comets, I shall speak of the ring of the *zodiacal light*, as with great probability belonging to our solar region, and after that of the *swarms of meteoric asteroids* which sometimes fall upon our earth, and with regard to whose existence, as bodies in space, by no means unanimous opinions prevail. As in accordance with the course adopted by Chladni, Olbers, Laplace, Arago, Sir John Herschel, and Bessel, I consider the aërolites to be of decidedly extra-terrestrial cosmical origin, I may venture, at the conclusion of the section upon the planets, confidently to express the expectation that, by continued accuracy in the observation of aërolites, fire-balls, and shooting-stars, the opposite opinion will disappear in the same way that the opinion, universally diffused up to the sixteenth century, as to the *meteoric* origin of the comets has long done. While these bodies were considered by the astrological corporation of "Chaldeans in Babylon," by the greater part of the Pythagorean school, and by Apollonius Myndius, as cosmical bodies reappearing at definite periods in long planetary orbits, the powerful anti-Pythagorean school of Aristotle and that of Epigenes, controverted by Seneca, declared the comets to be productions of meteorological processes in our atmosphere.[34]

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made since the death of the great man, in the *resolvability* of so many nebulous spots into crowded heaps of stars; the circumstance also that the comets have a portion of *reflected polarized* light, which the self-luminous bodies are destitute of. Compare *Cosmos*, vol. iii. pp. 192, 303, 315.

[34] There were divisions of opinion at Babylon in the learned

Analogous fluctuations between cosmical and terrestrial hypotheses, between universal space and the atmosphere, still lead at last to a more correct view of natural phenomena.

Chaldean school of astrologers, as well as among the Pythagoreans, and, properly speaking, among all ancient schools. Seneca (*Nat. Quæst.* vii. 3) quotes the antagonistic evidence of Apollonius Myndius and Epigenes. The latter is seldom mentioned, yet Plinius (vii. 57,) represents him as "gravis auctor in primis," as does also, without praise, Censorius *de die natali*, cap. xvii. and Stob. *Ecl. Phys.* i. 29, p. 586, ed. Heeren. (Compare Lobeck, *Aglaoph.* xi.) Diodorus (xv. 50) believes that the universal and prevailing opinion among the Babylonian astrologers (the Chaldeans), was that the comets reappeared at definite times in their *certain* orbits. The division which prevailed between the Pythagoreans, as to the planetary nature of the comets, and which is mentioned by Aristotle (*Meteorol.* lib. i. cap. vi. 1,) and Pseudo-Plutarch (*de Plac. Philos.* lib. iii. cap. ii.), extended, according to the former (*Meteorol.* i. 8, 2), also to the nature of the *Milky Way*, the forsaken course of the Sun, or of the overthrown Phaëton. (Compare also Letronne, in the *Mém. de l'Acad. des Inscriptions*, 1839, tom. xii. p. 108.) By some of the Pythagoreans the opinion of Aristotle was advanced, "that the comets belonged to the number of those planets which, like Mercury, only became visible after a long time when rising in the course above the horizon." In the extremely fragmentary Pseudo-Plutarch it is said, that they "ascend at definite times after a complete revolution." A great deal of matter contained in separate works, referring to the nature of the comets, has been lost to us, that of Arrian, which Stobæus employed; of Charimander, whose mere name has been retained only by Seneca and Pappus. Stobæus brings forward, as the opinion of the Chaldeans (*Eclog.* lib. i. cap. xxv. p. 61, *Christ. Plantinus,*) that the reason the comets remain so seldom visible to us, is because they hide themselves in the *depths* of the ether (of space), like the fish in the depths of the ocean. The most graceful, and in spite of its rhetorical colouring, the best founded opinion of antiquity, and the one corresponding most closely with present views, is that of Seneca. In the *Nat. Quæst.* lib. vii. cap. xxii. xxv. and xxxi.

we read, "Non enim existimo Cometem subitaneum ignem sed inter æterna opera naturæ. Quid enim miramur, cometas, tam rarum mundi spectaculum, nondum teneri legibus certis? nec initia illorum finesque patescere, quorum ex ingentibus intervallis recursus est? Nondum sunt anni quingenti, ex quo Græcia . . . . stellis numeros et nomina fecit. Multæque hodie sunt gentes, quæ tantum facie noverit cœlum; quæ nondum sciant, cur Luna deficiat, quare obumbretur. Hoc apud nos quoque nuper ratio ad certum perduxit. Veniet tempus, quo ista, quæ nunc latent, in lucem dies extrahat et longioris ævi diligentia. Veniet tempus, quo posteri nostri tam aperta nos nescisse mirentur. Eleusis servat, quod ostendat revisentibus. Rerum natura sacra sua non simul tradit. Initiatos nos credimus; in vestibulo ejus hæremus. Illa arcana non promiscue nec omnibus patent, reducta et in interiore sacrario clausa sunt. Ex quibus aliud hæc ætas, aliud quæ post nos subibit, dispiciet. Tarde magna proveniunt." "For I do not think that comets are a casual outburst of fire, but belong to the eternal works of nature. For why should it surprise us that comets, so rare a phenomenon, should not yet be subject to the regulation of any known laws? and that their origin and ends should be hid from us, who see them only at immense intervals? It is not yet five hundred years since Greece gave names and number to the stars. And to this day there are many nations who know nothing of the heavenly bodies but as they appear to the eye, who are still ignorant of the causes of the waves and eclipses of the moon; even we ourselves have only lately attained an accurate knowledge of these phenomena. The time will arrive when the diligence of a remoter age shall throw light on subjects which are now involved in obscurity. The time will arrive when our posterity will wonder at our ignorance of things so plain to them. Eleusis reserves her favours for those who repeat their visits. Nature does not permit us to explore her sanctuary all at once. We believe we are initiated; whereas we halt at the very threshold. Those mysteries are not revealed indiscriminately to all; they are laid up and enshrined within the penetralia. Some are revealed to the men of our age; some to those who shall come after us. Great results proceed slowly."

IV

THE RING OF THE ZODIACAL LIGHT.

In our solar system, so rich in varieties of form, the existence, place, and configuration of many individual members have been discovered, since scarcely a century and a half, and at long intervals of time: first, the subordinate, or *particular systems*, in which, analogous to the principal system of the Sun, smaller spherical cosmical bodies revolve round a larger; then concentric *rings* round one, and that indeed one of the less dense and exterior planets which possesses the greatest number of satellites; then the existence, and probably material cause, of the mild, pyramidal-formed, *zodiacal light*, very visible to the naked eye; then the mutually intersecting orbits of the so-called *small planets*, or *asteroids*, inclosed between the regions of two principal planets, and situated beyond the zodiacal zone; finally, the remarkable group of *interior comets*, whose aphelia are smaller than those of Saturn, Uranus, and Neptune. In a cosmical representation of universal space, it is necessary to call to mind the *difference* of the members of the solar system, which by no means excludes similarity of *origin* and lasting dependence upon the moving forces.

Great as is the obscurity which still envelops the material cause of the zodiacal light, still, however, with the mathematical certainty that the solar atmosphere can not reach beyond $\frac{9}{20}$ of the distance of Mercury, the opinion supported by Laplace, Schubert, Arago, Poisson, and Biot, according to

which the zodiacal light radiates from a vapoury, flattened ring, freely revolving in space between the orbits of Venus and Mars, appears in the very deficient state of observation to be the most satisfactory. The outermost limits of the Sun's atmosphere, like that of Saturn (a subordinate system), could only extend to that point where the attraction of the universal or partial central body exactly balanced the centrifugal force; beyond this point the atmosphere must escape at a tangent, and continue its course either aggregated into spherical planets and satellites, or, when not aggregated into spheres, as solid and vaporous rings. From this point of view the *ring of the zodiacal light* comes within the category of planetary forms, which are subject to the universal laws of formation.

From the small progress which this neglected part of our astronomical knowledge makes on the path of observation, I have little to add to that which I derived from the experience of others and myself, and have previously developed in the *Delineation of Nature* (vol. i. pp. 127–134; vol. iv. p. 308). If, 22 years before Dominique Cassini, to whom the first detection of the zodiacal light is erroneously ascribed, Childrey, the chaplain of Lord Henry Somerset, had already recommended this phenomenon to the attention of astronomers in his *Britannica Baconica*, published in 1661, as one which had previously been unnoticed and observed by him during several years, in February and the commencement of March; so must I also mention (according to a remark of Olbers) a letter which Rothman wrote to Tycho, from whence it results that Tycho saw the zodiacal light as early as the end of the sixteenth century, and considered it to be an abnormal spring-evening twilight. The strikingly greater luminous intensity of this phenomenon in Spain, upon the coasts of Valencia and the plains of New Castile, first incited me to continuous observation before I left Europe. The strength of

the light—it might almost be called illumination—increased surprisingly the more I approached the equator in South America and the South Sea. In the continually dry, clear air of Cumana, in the grass-steppes (*llanos*) of Caracas, upon the elevated plains of Quito and the Mexican seas, especially at heights from eight to twelve thousand feet, where I could remain longer, the brightness sometimes exceeded that of the most beautiful sparks of the Milky Way between the forepart of Argus and Sagittarius, or, to speak of our part of the hemisphere, between the Eagle and the Swan.

Upon the whole, the brightness of the zodiacal light did not appear to me to increase at all perceptibly with the *elevation* of the point whence it was seen, but much rather to depend *principally* upon the interior variability of the phenomenon itself—upon the greater or less intensity of the light-giving process: as is shown by my observations in the South Sea, in which indeed a reflection was remarked, like that seen on the going down of the Sun. I say *principally*, since I do not deny the possibility of a simultaneous influence of the condition of the air (greater or less diaphanity) of the higher strata of the atmosphere, while my instruments indicated in the lower strata, no hygrometric variations, or much rather favourable ones. Advances of our knowledge of the zodiacal light are to be expected especially from the tropics, where the meteorological processes attain the highest degree of uniformity or regularity in the periodical recurrence of the changes. The phenomenon is there perpetual; and a careful comparison of observations at points of different elevation and under different local conditions, would, with the application of the theory of probabilities, decide what should be ascribed to cosmical light-processes, what to merely meteorological influences.

It has been repeatedly affirmed that in Europe scarcely any zodiacal light, or only a feeble trace of it, could be seen in

several successive years. Has the light appeared proportionately weakened in such years in the equinoctial zone also? The investigation must not, however, be restricted to the statement of the configuration according to the distance from known stars or direct measurements. The intensity of the light, its uniformity or probable intermittence (darting and flashing), its analysis by the polariscope, should be especially investigated. Arago (*Annuaire pour* 1836, p. 289) has already pointed out that the comparative observation of Dominique Cassini, would perhaps clearly prove "que la supposition des intermittences de la diaphanité atmosphérique ne saurait suffire à l'explication des variations signalées par cet astronome." "That the supposition of intermittent variations in the diaphanity of the atmosphere, would not suffice for the explanation of the changes indicated by that astronomer."

Immediately after the observations of this great astronomer at Paris, and of his friend Fatio de Duillier, an inclination to similar labours showed itself in Indian travellers (Father Noël, de Bèze and Duhalde); but isolated reports (for the greater part only describing the gratification experienced at the unusual prospect) are not available for the sound discussion of the causes of the variability. It is not by rapid travels or so-called voyages round the world, as the labours of the active Horner have recently shown (*Zach, Monatl. Corresp.* bd. x. pp. 337–340), that the deserved object is to be obtained. It is only by a permanent stay of several years in some tropical country, that the problem of variable configuration and luminous intensity can be solved. Therefore, the most is to be expected for the subject which now occupies us, as well as for the entire science of meteorology, from the ultimate diffusion of scientific culture throughout the equinoctial world,—the former Spanish America,—where large populous towns, Cuzco, La Paz, Potosi, are situated between 10,700 and 12,500

feet above the level of the sea. The numerical results which Houzeau was able to obtain, though certainly based upon only a small number of observations, make it probable that the major axis of the zodiacal light no more coincides with the plane of the Sun's equator, than the vapoury mass of the ring whose molecular condition is unknown to us extends beyond the Earth's orbit. (*Schum. Astr. Nachr.* No. 492.)

V.

FALLING STARS, FIRE-BALLS, AND METEORIC STONES.

SINCE the spring of 1845, when I published the *Delineations of Nature*, or the general survey of cosmical phenomena, the previous results of the observation of aërolites and periodic streams of falling stars, have been abundantly extended and corrected. Much has been subjected to a stricter and more careful criticism; especially the discussion, so important for the whole of this mysterious phenomenon, of the *divergence*, *i. e.* the situation of the point of departure in the recurring epochs of swarms of falling stars. The number of these epochs, also, of which for a long time the *August* and *November periods* alone attracted attention, has been increased by recent observations, whose results present a high degree of probability. From the meritorious labours, first of Brandes, Benzenberg, Olbers and Bessel, subsequently of Erman, Boguslawski, Quetelet, Feldt, Saigey, Edward Heis, and Julius Schmidt, corresponding measurements have been commenced; and a more generally diffused mathematical spirit has rendered it more difficult, through self-deception, to make uncertain observations agree with a preconceived theory.

The progress in the study of fire-meteors would be so much the quicker in proportion as facts are impartially separated from opinions, and details put to the test; but not everything discarded as being imperfectly observed which cannot yet be explained. It appears to me most important

to separate the *physical* relations from the *geometrical* and *numerical* relations, which latter are upon the whole capable of being established with greater certainty. To this class belong altitude, velocity, individuality, and multiplicity, of the points of departure when divergence is detected; the mean number of fire-meteors in *sporadic* or *periodic* appearances reduced according to their frequency to the same measure of time, the magnitude and configuration in connection with the time of year, or with the length of time from midnight. The investigation of both kinds of relations, the *physical* and the *geometrical*, will gradually lead to one and the same end,—to *genetic* considerations as to the intrinsic nature of the phenomenon.

I have already pointed out the fact that, *upon the whole, intercourse* with universal space and its contents is restricted to that which we acquire through oscillations exciting *light* and *heat*, as well as by the mysterious attractive forces which remote *masses* (cosmical bodies) exercise upon our terrestrial globe, its oceans and atmospheric envelope, according to the quantity of their material particles. The luminous vibrations which proceed from the smallest telescopic stars of a *resolvable* nebula, and of which our eyes are sensible, brings us a *testimony of the oldest existence of matter* in the same way that it mathematically demonstrates to us the certain knowledge of the *velocity* and *aberration* of light.[1] A sensation of light from the *depths* of the star-filled *space of heaven*

[1] The aspect of the starry heavens presents to us objects of *unequal date*. Much has long ceased to exist before the knowledge of its presence reaches us; much has been otherwise arranged. *Cosmos*, vol. i. p. 144, and vol. iii. p. 90, and note. (Compare also Bacon, *Nov. Organ.* Lond. 1733, p. 371, and Will. Herschel, in the *Philos. Transact.* for 1802, p. 498.)

leads us back, by means of a chain of ideas, through myriads of centuries into the *depths of antiquity*. Although the impression of light which streams of falling stars, exploding aërolite fire-balls, or similar fire-meteors give, may be of an entirely different nature; although they may not take fire until they enter the Earth's atmosphere, still the falling aërolites present the solitary instance of a *material* connection with something *which is foreign to our planet.* We are astonished "at being able to touch, weigh, and chemically decompose metallic and earthy masses which belong to the outer world, to celestial space," to find in them the minerals of our native earth, making it probable, as the great Newton conjectured, that the materials which belonged to one group of cosmical bodies are for the most part the same.[3]

For the knowledge of the most ancient falls of aërolites which are determined with chronological accuracy, we are indebted to the industry of the all-registering Chinese. Such reports reach back to the year 644 before our era; therefore to the time of Tyrtæus and the second Messenian war of the Spartans, 179 years before the fall of the enormous meteoric mass near Ægos Potamos. Edward Biot has found in Ma-tuan-lin, which contains extracts from the astronomical section of the most ancient annals of the empire, sixteen falls of aërolites for the epoch from the middle of the seventh century before Christ up to 333 years after Christ; while the Greek and Roman authors mention only four such phenomena during the same space of time.

It is remarkable that the Ionian school, in accordance with our present opinions, early assumed the *cosmical* origin of meteoric stones. The impression which such a magnificent phenomenon as that of Ægos Potamos (at a point which became still more celebrated sixty-two years afterwards by

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[3] *Cosmos*, vol. i. p. 120.

the conclusion of the Peloponnesian war by the victory of Lysander over the Athenians), made upon all the Hellenic races, must have exerted a decisive and not sufficiently regarded influence upon the direction and development of the Ionian *physiology*.[3] Anaxagoras of Clazomena was at the mature age of thirty-two years when that event of nature took place. According to him, the stars are masses torn away from the earth by the violence of the *rotation* (Plut. *de plac. Philos.* iii. 13). He considers that the whole heavens may be composed of stones (Plato, *de Legib.* xii. p. 967). The stony solid bodies are made to glow by the fiery ether, so that they reflect the light communicated to them by the ether. Lower than the Moon, and still *between her and the Earth*, there move, says Anaxagoras, according to Theophrastus (Stobæus, *Eclog. Phys.* lib. i. p. 560), yet *other dark bodies* which can also produce eclipses of the Moon (Diog. Laert. ii. 12; Origenes, *Philosophum*, cap. viii.) Diogenes of Apollonia who, if he is not a disciple of Anaximenes,[4] still probably belongs to an epoch between Anaxagoras and Democritus, expresses himself still more distinctly as to the structure of the world, and, as it were, more moved by the impression of the great fall of aërolites. According to him, as I have already mentioned, "*invisible* (dark) masses of stone move with the visible stars, and remain on that account unknown. The former sometimes fall upon the earth, and are extinguished; as happened with the *stony star* which fell near Ægos Potamos." (Stob. *Eclog.* p. 508.)[5]

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[3] See the opinions of the Greeks as to the falls of meteoric stones, in *Cosmos*, vol. i. p. 122; vol. ii. p. 690, note.

[4] Brandis, *Gesch. der Griechisch-Röm. Philosophie*, tom. i. pp. 272–277, against Schleiermacher, in the *Abhandl. der Berl. Akad.* from the year 1804–1811 (Berl. 1815), pp. 79–124.

[5] When Stobæus in the same passage (*Eclog. Phys.* p. 508) ascribes to the Apollonian that he had called the stars *pumice-*

The "opinion of some physicists" as to fiery meteors (falling stars and aërolites), which Plutarch develops in detail in the life of Lysander (cap. xii.), is precisely that of the Cretan Diogenes. "Falling stars," it is said there, "are not ejections and waste of the ethereal fire which, when they enter our atmosphere, are extinguished after their ignition; they are much rather the *off-shoots* of celestial bodies, of such a nature that by a slackening of the revolution they are shot down."[8] We find nothing of this view of the structure of the universe, this assumption of *dark* cosmical bodies which fall

stone-like bodies (therefore porous stones), the occasion for this term might have been the idea so generally diffused in antiquity, that all celestial bodies were nourished by moist *exhalations*. The Sun gives back again what is *absorbed*. (Aristot. *Meteorol.* ed. Ideler, tom. i. p. 509; Seneca, *Nat. Quæst.* lib. iv. 2.) The pumice-stone-like cosmical bodies have their peculiar exhalations. "These, which cannot be seen so long as they wander round in the celestial space, are *stones;* they ignite and are extinguished again when they fall to the earth." (Plut. *de Plac. Philos.* ii. 13.) Pliny considers the fall of meteoric stones as frequent (Plinius, ii. 59): "Decidere tamen crebro, non erit dubium." He also knew that the fall in clear air produced a loud noise (ii. 43). The apparently analogous passage in Seneca, in which he mentions Anaximenes (*Nat. Quæst.* lib. ii. 17), refers probably to the thunder in a storm-cloud.

[8] This remarkable passage (Plut. *Lys.* cap. xii.) literally translated, runs thus: "But there is another and more probable opinion which holds that falling stars are not emanations or detached parts of the elementary fire, that go out the moment they are kindled, nor yet a quantity of air bursting out from some compression, and taking fire in the upper regions; but that they are really heavenly bodies which, from some relaxation of the rapidity of their motion, or by some irregular concussion, are loosened and fall, not so much upon the habitable part of the globe as into the ocean, which is the reason that their substance is seldom seen."

upon our earth, in the doctrines of the old Ionic schools, from Thales and Hippocrates to Empedocles.[7] The impression made by the occurrence of nature in the 78th Olympiad, appears to have powerfully called forth the idea of the fall of dark masses. In the more recent Pseudo-Plutarch, (Plac. ii. 13,) we read merely that the Milesian Thales considered "all stars to be *earthy* and *fiery* bodies (γεώδη καὶ ἔμπυρα)." The endeavours of the *earlier* Ionic physiology were directed to the discovery of the primitive cause of all things, formation by mixture, gradational change and transition of one kind of matter into another: to the processes of *genetic development* by solidification or dilution. The *revolution* of the sphere of the heavens "which holds the Earth firmly in the centre," was already conceived by Empedocles as an actively moving cosmical force. Since, in these first attempts at physical theories, the ether, the *fire-air* (and indeed fire itself), represents the expansive force of heat, so the idea of the propelling revolution rending fragments from the Earth, became connected with the lofty *region of the ether*. Therefore Aristotle calls (*Meteorol.* i. 339, Bekker) the ether "the eternally moving body,"[8] as it were the immediate substratum of motion; and seeks for etymological reasons for this assertion. On this account we find in the biography of Lysander, "that the relaxation of the centrifugal force causes the *fall* of celestial bodies;" as also in another place, where Plutarch, evidently alluding again to opinions of Anaxagoras, or Diogenes of Apollonia (*De facie in orbe Lunæ*, pp. 9–23), puts forward the assertion "that

[7] With regard to absolutely *dark* cosmical bodies, or such in which the *light-process* ceases (*periodically?*); as to the opinions of moderns (Laplace and Bessel); and Bessel's observation, confirmed by Peters in Königsberg, of a variability of the *proper motion* of Procyon: see *Cosmos*, vol. iii. pp. 222, 225.

[8] Compare *Cosmos*, vol. iii. pp. 35–39.

the Moon would fall to the Earth like a stone in a sling, if its centrifugal force ceased."[9] Thus we see in this simile, after the assumption of a *centrifugal* revolution which Empedocles perceived in the apparent rotation of the celestial sphere, a *centripetal force* gradually arise as an ideal antithesis. This force was specially and most distinctly described by the acute interpreter of Aristotle, Simplicius (p. 491, Bekker). He explains the *non-falling* of the celestial bodies thus: "that the centrifugal force predominates over the proper *fall-force, the drawing downwards*." These are the first conjectures respecting active central forces; and the Alexandrian, Johannes Philoponus, a disciple of Ammonius Hermea, probably of the sixth century, as it were, recognizing also the *inertia* of matter, first ascribes "the motion of the revolutionary planets to a *primitive impulse*," which he ingeniously (*De creatione Mundi*, lib. i. cap. xii.), unites with the idea of the "fall, a tendency of all heavy and light bodies towards the Earth." We have thus endeavoured to show how a great phenomenon of nature and the earliest purely *cosmical explanation* of a fall of aërolites essentially contributed in Grecian antiquity, step by step, but certainly not by mathematical reasoning, to develop the germ which, fostered by the intellectual labours of the following centuries, led to Huygens' discovery of the laws of circular motion.

Commencing from the *geometrical* relations of the periodic (not sporadic) falling stars, we direct our attention especially to what recent observations as to the *divergence* or *point of departure*, of the meteors, and their *entirely planetary velocity*,

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[9] The remarkable passage alluded to in the text in Plutarch, *De facie in orbe Lunæ*, p. 923, is literally translated, "However, the motion of the Moon and the violence of the revolution itself prevents it from falling, just as things placed in a sling are prevented from falling by their motion in a circle."

have made known. Both these circumstances, divergence and velocity, characterize them with a high degree of probability as luminous bodies which present themselves independently of the Earth's rotation, and penetrate into our atmosphere *from without*, from space. The North American observations of the *November period* on the occasion of the falls of stars in 1833, 1834, and 1837, indicated as the *point of departure* the star γ Leonis; the observations of the August phenomenon, in the year 1839, Algol in Perseus, or a point between Perseus and Taurus. These centres of divergence were about the constellations towards which the Earth moved at the same epoch.[10] Saigey, who has submitted the American observations of 1833 to a very accurate investigation, remarks that the fixed radiation from the constellation Leo, is only observed properly after midnight, in the last 3 or 4 hours before daybreak; that of eighteen observers between the town of Mexico and Lake Huron, only ten perceived the same general point of departure of the meteors,[11] which Denison Olmsted, Professor of Mathematics in Newhaven (Massachusetts,) indicated.

The excellent work of Edward Heis of Aix-la-Chapelle, which presents in a condensed form the very accurate observations of falling stars made by himself during ten years, contains results as to the *phenomena of divergence*, which are so much the more important as the observer has discussed them with mathematical strictness. According to him,[12] "the falling stars of the *November period* present the peculiarity that their paths are more dispersed than those of the *August period*.

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[10] *Cosmos*, vol. i. p. 105–106.

[11] Coulvier-Gravier and Saigey, *Recherches sur les Etoiles filantes*, 1847, pp. 69–86.

[12] "The *periodical* falling stars and the results of the phenomena deduced from the observations carried on during the last ten years at Aix-la-Chapelle by Edward Heis," 1849, pp. 7 and 26–30.

In each of the two periods there were simultaneously several points of departure by no means always proceeding *from the same constellation*, as there was too great a tendency to assume since the year 1833." Besides the *principal point of departure of Algol in Perseus*. Heis finds in the *August* periods of the years 1839, 1841, 1842, 1843, 1844, 1847, and 1848, two others in Draco and the *North Pole*.[13] "In order to deduce accurate results as to the points of departure of the paths of the falling stars in the *November periods* for the years 1839, 1841, 1846, and 1847, for the four points (Perseus, Leo, Cassiopeia, and the Dragon's Head), the mean path belonging to each was drawn upon a thirty-inch celestial globe, and in every case the position of the point ascertained from which the greatest number of paths proceeded. The investigation showed that of 407 of the falling stars indicated *according to their paths*, 171 came from Perseus, near the star η in Medusa's Head, 83 from Leo, 35 from Cassiopeia, near the changeable star α, 40 from the Dragon's Head, but full 78 from undetermined points. The number of falling stars issuing from Perseus consequently amounted to nearly double those from Leo."[14]

[13] The statement of the *North* Pole being a centre of radiation in the August period is founded only upon the observations of the one year 1839 (10th of August). A traveller in the East, Dr. Asahel Grant, reports from Mardin in Mesopotamia, "that about midnight the sky was as it were furrowed with falling stars, all of which proceeded from the *region of the polar star*." (Heis, p. 28, from a letter of Herrick's in Quetelet's and Grant's Diary.)

[14] This preponderance of Perseus over Leo, as a point of departure, did not by any means obtain in the observations at Bremen on the night of the $\frac{13}{14}$ November, 1838. A very experienced observer, Roswinkel, saw, on the occasion of a very abundant fall of shooting stars, almost all the paths proceed from Leo and the southern part of Ursa Major; while in

The divergence from Perseus has consequently shown itself *in both* periods as a very remarkable result. An acute observer, Julius Schmidt, attached to the Observatory at Bonn, who has been occupied with meteoric phenomena for eight or ten years, expresses himself upon this subject with great decision in a letter to me (July, 1851): "If I deduct from the abundant falls of shooting stars in November, 1833, and 1834, as well as from subsequent ones, that kind in which the point in Leo sent out whole swarms of meteors, I am at present inclined to consider the *Perseus point* as that point of divergence which presents not only in August, but throughout the *whole year*, the most meteors. This point is situated, according to the result deduced from 478 observations by Heis, in Rt. Asc. 50°·3 and Decl. 51°·5 (holding good for 1844–6). In November, 1819 (from the 7th to the 14th), I saw some hundreds more shooting stars than I have ever remarked since 1841. Of these only a few upon the whole came from Leo; by far the greater number belonged to the constellation of Perseus. It follows from this, as it appears to me, that the *great* November phenomenon of 1799 and 1833 did not appear at that time (1841). Olbers also believes that the maximum November appearance has a period of thirty-four years (*Cosmos*, vol. i. p. 115). If the directions of the meteor-paths are considered in their full complication and periodical recurrence, it is found that there are certain *points of divergence*

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the night of the $\frac{12}{13}$ of November, on the occasion of a fall but little less abundant, only four paths proceeded from Leo. Olbers (Schum. *Astr. Nachr.* no. 372) adds very significantly: On this night paths did not appear at all parallel to each other, and showed no relation to Leo: they appear, on account of the want of parallelism, to belong to the sporadic and the periodic class of falling stars. The proper November period was, however, certainly not to be compared in brilliancy with those of the years 1799, 1832, and 1833."

which are always represented, others which appear only sporadically and changeably."

Whether, moreover, the different points of divergence alter with the years—which, if *closed rings* are assumed, would indicate an alteration in the situation of the ring in which the meteors move—cannot at present be determined with certainty from the observations. A beautiful series of such observations by Houzeau (during the years 1839 to 1842) appears to offer evidence against a progressive alteration.[15] Edward Heis[16] has very correctly remarked that in Grecian and Roman antiquity, attention had already been directed to a certain temporary uniformity in the *direction* of shooting stars darting across the sky. That direction was then considered as the result of a wind already blowing in the higher regions of the atmosphere, and predicted to the sailors an approaching current of air descending thence into the lower regions.

If the *periodic* streams of shooting stars are distinguished from the *sporadic* by the frequent parallelism of their paths, proceeding from one or more points of divergence, a second criterion of them is the numerical—the number of individual meteors referred to a definite measure of time. We come here to the much-disputed question of the distinction of an extraordinary from an ordinary fall of shooting stars. Two

[15] Saigey, p. 151; and upon Erman's determination of the *points of convergence* diametrically opposed to the points of divergence, pp. 125–129.

[16] Heis, *Period. Sternschn.* p. 6. (Compare also Aristot. *Problem.* xxvi. 23; Seneca, *Nat. Quæst.* lib. i. 14: "Ventum significat stellarum discurrentium lapsus, et quidem ab ea parte qua erumpit.") I have myself long believed in the influence of the wind upon the direction of the shooting stars, especially during my stay at Marseilles at the time of the Egyptian expedition.

excellent observers, Olbers and Quetelet, have given as the mean number of meteors which can be reckoned hourly in the range of vision of one person upon not extraordinary days, the former five to six, the latter eight meteors.[17] For the discussion of this question, which is as important as the determination of the laws of motion of shooting stars, in reference to their direction, a great number of observations are required. I have therefore referred with confidence to the already-mentioned observer, Herrn Julius Schmidt at Bonn, who, long accustomed to astronomical accuracy, takes up with his peculiar energy the whole phenomena of meteors—of which the formation of aërolites and their fall to the Earth appear to him merely a special phase, the rarest, and therefore not the most important. The following are the principal results of the communications which I requested from him.[18]

"The mean number of *sporadic* shooting stars appearing there has been found from many years of observation (between 3 and 8 years), *a fall of from* 4 *to* 5 *in the hour.* This is the ordinary condition when nothing periodic occurs. The mean numbers of *sporadic* meteors in the individual months, give for the hour, January, 3·4; February,——; March, 4·9; April, 2·4; May, 3·9; June, 5·3; July, 4·5; August, 5·3; September, 4·7; October, 4·5; November, 5·3; December, 4·0.

"Of the *periodic* meteors there may be *expected*, on the average, in each hour, *above* 13 *or* 15. For a single period, that of August, the stream of Laurentius presented the following gradual increases from sporadic to periodic, upon an average of from 3 to 8 years of observation.

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[17] *Cosmos*, vol. i. p. 100.

[18] All that is marked in the text with inverted commas I am indebted for to the friendly communication of Herrn Julius Schmidt, attached to the observatory at Bonn. With regard to his earlier works of 1844, see Saigey, p. 159.

Time.	Number of meteors in one hour.	Number of years.
6th of August	6	1
7th „	11	3
8th „	15	4
9th „	29	8
10th „	31	6
11th „	19	5
12th „	7	3

The last year gave for the hour, notwithstanding the clear moonlight:—

On the 7th of August	3 Meteors
8th „	8 „
9th „	16 „
10th „	18 „
11th „	3 „
12th „	1 Meteor.

(According to Heis, there were observed on the 10th of August:—

1839 in one hour	160 Meteors
1841	43 „
1841	50 „

In the August meteor-stream in 1842, there fell at the time of the maximum, in ten minutes, 34 shooting stars). All these numbers refer to the circle of vision of one observer. Since the year 1838, the November falls have been less brilliant. (On the 12th of November, 1839, Heis still counted hourly 22 to 35 meteors; likewise on the 13th of November, 1846; upon the average 27 to 33.) So variable is the abundance of the periodic streams in individual years; but the number of the falling meteors always remains considerably greater than in ordinary nights; which show in one hour only

4 or 5 sporadic falls. The meteors appear to be the most seldom in January (calculating from the 4th), February and March.[19]

"Although the *August* and *November periods* are justly the most celebrated, still since the shooting stars have been observed with greater accuracy, as to their number and parallel direction, yet five others have been discovered.

January: during the first days between the 1st and 3rd; probably somewhat doubtful.

April: 18th or 20th? already conjectured by Arago. (Great streams: 25th of April, 1095, 22nd of April 1800 20th of April, 1803; *Cosmos*, vol. i. pp. 113–114. *Annuaire pour* 1836, p. 297.)

May: 26th?

July: 26th to the 30th; Quetelet. Maximum properly between the 27th and 29th of July. The most ancient Chinese observations gave Edward Biot (unfortunately too soon taken away) a general maximum between the 18th and 27th of July.

August, but *before* the Laurentius stream, especially between the 2nd and 5th of the month. For the most part no regular increase is remarked from the 20th of July to the 10th of August.

——— The *Laurentius stream* itself, Musschenbroek and Brandes (*Cosmos*, vol. i. p. 112, and note). Decided maximum on the 10th of August; observed for many years. (According to an old tradition which is diffused among the mountain-regions about Pelion in Thessaly, on the feast of the Transfiguration, the 6th of March, the

[19] I have, however, myself observed a considerable fall of shooting stars on the 16th of March, 1803, in the South Sea (Lat. 13¼° N.). Also 687 years before our era, two meteor-streams were seen in China, in the month of March (*Cosmos*, vol. i. p. 116).

heavens open during the night, and the lights (καvδήλια) appear in the midst of the opening; Herrick in *Silliman's, Amer. Journal*, vol. xxxvii. 1839, p. 337; and Quetelet in the *Nouv. Mém. de l'Acad. de Bruxelles*, tom. xv. p. 9.)

October: the 19th and the days about the 26th; Quetelet, Boguslawski in the "*Arbeiten der schles. Gesellschaft für vaterl. Cultur.*" 1843, p. 178; and Heis, p. 83. The latter instituted observations on the 21st of October, 1766, 18th October, 1838, 17th October, 1841, 24th of October, 1845, 11th–12th October, 1847, and 20th–26th October, 1848. (See remarks upon three *October phenomena*, in the years 902, 1202 and 1366, *Cosmos*, vol. i. p. 116, and note.) The conjecture of Boguslawski, that the Chinese swarms of meteors, of the 18th and 27th of July, and the fall of shooting stars of the 21st of October (O.S.) 1366, may be the now *advanced*, August and November periods, loses much of its weight after the recent experience of 1838–1848.[20]

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[20] An entirely similar fall of shooting stars as that which the younger Boguslawski found for October 21st, 1366, (o.s.), in Benesse de Horovic. *Chronicon Ecclesiæ Pragensis* (*Cosmos*, vol. i. p. 116), is fully described in the famous historical work of Duarte Nunez do Lião (*Chronicas dos Reis de Portugal reformados*, pt. i. Lisb. 1600, f. 187), but placed in the night of the 22nd to 23rd of October (o.s.) Were there two streams seen in Bohemia, and on the Tagus, or has one of the chroniclers erred in a day? The following are the words of the Portuguese historian: "Vindo o anno de 1366 sendo andados xxii. dias do mes de Octubro, tres meses antes do fallecimento del Rei D. Pedro (de Portugal), se fez no ceo hum movimento de estrellas, qual os homees não virão nem ouvirão. E foi que desda mea noite por diante correrão todalas strellas do Levante para o Ponente, e acabado de serem juntas começarão a correr humas para huma parte e

November: 12th–14th, very seldom the 8th or 10th. The great fall of meteors of 1799 in Cumana on the 11th–12th of November, which Bonpland and I have described, so far gave occasion *to believe in periodic appearances upon certain days*, that on the occasion of the great fall of meteors in 1833 (November 12th–13th) the phenomenon of the year 1799 was called to mind.[n]

outras para ontra. E despois descerão do ceo tantes e tam spessas, que tanto que forão baxas no ar, parecião grandes fogueiras, e que o ceo e o ar ardião, e que a mesma terra queria arder. O ceo parecia partido em muitas partes, alli onde strellas não stavão. E isto durou per muito spaço. Os que isto vião, houverão tam grande medo e pavor, que stavão como attonitos e cuidavão todos de ser mortos, e que era vinda a fim do mundo." "In the year 1366, and xxii days of the month of October being past, three months before the death of the king, Dom Pedro, (of Portugal), there was in the heavens a movement of stars, such as men never before saw or heard of. At midnight, and for some time after, all the stars moved from the east to the west; and after being collected together, they began to move, some in one direction, and others in another. And afterwards they fell from the sky in such numbers, and so thickly together, that as they descended low in the air, they seemed large and fiery, and the sky and the air seemed to be in flames, and even the earth appeared as if ready to take fire. That portion of the sky where there were no stars, seemed to be divided into many parts, and this lasted for a long time. Those who saw it were filled with such great fear and dismay, that they were astounded, imagining they were struck dead, and that the end of the world had come."

[n] *Nearer* epochs of comparison might have been brought forward, if they had been known at that time; for example, the streams of meteors observed by Klöden, 1823, Nov. 12th–13th, in Potsdam; by Bérard, 1831, Nov. 12th–13th, on the Spanish coast; and by Graf Suchtelu, at Orenberg, 1832, Nov. 12th–13th (*Cosmos*, vol. i. p. 112; and Schum. *Astr. Nachr.* no. 303, p. 242). The great phenomenon of

December: 9th–12th; but in 1798, according to Brandes' observation, December the 6th–7th; Herrick, in Newhaven, 1838, Dec. 7th–8th; Heis, 1847, December 8th and 10th.

the 11th and 12th of November, which Bonpland and I have described (*Voyage aux Régions Equinoxiales,* liv. iv. chap. x, tom. iv. p. 34, 53rd ed. 8vo.), lasted from two to four o'clock in the morning. Upon the whole journey which we made through the forest region of the Orinoco southwards, as far as Rio Negro, we found that the enormous fall of meteors had been seen by the missionaries, and in some cases recorded in the church-books. In Labrador and Greenland, it threw the Esquimaux into a state of utter amazement as far as Lichtenau and New Herrnhut (Lat. 64° 14′). At Itterstadt, near Weimar, the pastor Zeising saw the same phenomenon that was at the same time visible under the equator, and near the north polar circle in America. Since the periodicity of the *St. Laurentius stream,* August 10th, did not attract general attention until long after the *November period* had, I have carefully placed together all the considerable and accurately-observed falls of shooting stars on the 12th–13th November known to me up to 1846. There are 15: 1799, 1818, 1822, 1823; 1831–1839 every year; 1841 and 1846. I exclude those falls of meteors which differ by one or two days: such as those of the 10th of November, 1787, 8th November, 1813. Such a periodicity closely connected with individual days is so much the more wonderful, as bodies of such a small mass are easily exposed to disturbances, and the breadth of the ring in which the meteors are supposed to be contained may surround the Earth for some days. The most brilliant November streams took place in 1799, 1831, 1833, 1834. (In my description of the meteor of 1799, the largest fire-ball has ascribed to it a diameter of 1° and 1¼°, when it should be 1 and 1¼ *lunar diameter.*) This is also the place to mention the fire-ball which attracted the special attention of the director of the observatory at Toulouse, M. Petit, and whose revolution round the Earth he has calculated. (*Comptes Rendus,* 9 Août, 1847; and Schum. *Astr. Nachr.* No. 701, p. 71.)

"Eight or nine epochs of periodic meteoric streams, of which the last five are most certainly determined, are here recommended to the industry of observers. The streams of different months are not alone different from each other; in different years, also, the abundance and brilliancy of the same stream varies strikingly.

"The *upper* limits of the *height* of shooting-stars cannot be ascertained with accuracy, and Olbers considers all heights above 120 miles as being less certainly determined. The *lower* boundaries which were formerly (*Cosmos*, vol. i. p. 107) generally estimated at 16 miles (over 97,388 feet), must be greatly contracted. Some, according to measurement, descend very nearly to the level of the summit of Chimborazo and Aconcagua, to the distance of 4 geographical miles above the level of the sea. Heis remarked, on the contrary, a falling star seen simultaneously at Berlin and Breslau on the 10th of July, 1837, had, according to accurate calculation, a height of 248 miles when its light first became visible, and a height of 168 on its disappearance; others disappeared during the same night at a height of 56 miles. From the older labours of Brandes (1823), it follows that of 100 well-defined shooting-stars seen from two points of observation, 4 had an elevation of only 4 to 12 miles; 15 between 12 and 24 m.; 22 from 24 to 40; 35 (nearly one-third) from 40 to 60 m.; 13 from 40 to 80 m.; and only 11 (scarcely one-tenth) above 80 m. their heights being between 180 and 240 miles. From 4000 observations collected during nine years, it has been inferred with regard to the *colour* of the shooting-stars, that two-thirds are white, one-seventh yellow, one-seventeenth yellowish red, and only one-thirty-seventh green."

Olbers reports, that during the fall of meteors in the night of the 12th and 13th of November, in the year 1838, a beautiful northern light was visible at Bremen, which coloured large parts of the sky with an intense blood-red light. The

shooting-stars darting across this region maintained their white colour unaltered, whence it may be inferred that the northern light was further removed from the surface of the Earth than the shooting-stars were at that point where they became invisible. (Schum. *Astr. Nachr.* no. 372, p. 78.) The relative velocity of shooting-stars has hitherto been estimated at from 18 to 36 geographical miles a second, while the Earth has only a translatory velocity of 16·4 miles. (*Cosmos*, vol. i. p. 107 and note). Corresponding observations of Julius Schmidt at Bonn, and Heis at Aix-la-Chapelle (1849), gave as the actual minimum for a shooting-star, which stood 48 miles vertically above St. Goar, and shot over the Lake of Laach only 14 miles. According to other comparisons of the same observer, and of Houzeau in Mons, the velocity of four shooting-stars was found to be between 46 and 95 miles in the second, consequently two to five times as great as the planetary velocity of the Earth. The cosmical origin is indeed most strongly proved by this result, together with the constancy of the simple or multiple points of divergence, *i. e.* together with the circumstance, that periodic shooting-stars, independently of the rotation of the Earth, proceed during several hours from the same star, even when this star is not that towards which the Earth is moving at the same time. According to the existing measurements, fire-balls appear to move slower than shooting-stars; but it nevertheless remains striking that when the former meteors fall, they sink such a little way into the ground. The mass at Ensisheim in Alsace weighing 276 pounds (November 7th, 1492), penetrated only 3 feet, and the aërolite of Braunau (July 14th, 1847) to the same depth. I know of only two meteoric stones which have ploughed up the loose earth for 6 and 18 feet; these are the aërolites of Castrovillari, in the Abruzzi (February 9th, 1583), and that of Hradschina in the Agram district (May 6th, 1751).

Whether anything has ever fallen from the shooting-stars to the Earth, has been much discussed in opposite senses. The straw roofs of the parish Belmont (Département de l'Ain, Arondissement Belley) which were set on fire by a meteor in the night of November 13th, 1835, just at the epoch of the known November phenomenon, received the fire, as it appears, not from a falling shooting-star, but from a bursting fire-ball, which problematical aërolite is said to have fallen according to the statements of Millet d'Aubenton. A similar conflagration, caused by a fire-ball, occurred on the 22nd of March, 1846, about three o'clock in the afternoon, in the commune of St. Paul, near Bagnère de Luchon. Only the fall of stones in Angers (on the 9th of July, 1822,) was ascribed to a beautiful falling star seen near Poitiers. This phenomenon, not sufficiently described, deserves great attention. The falling stars resembled entirely the so-called *Roman* candles used in fireworks. It left behind it a straight streak, very narrow above, and very broad below, which lasted for ten or twelve minutes with great brilliancy. Seventeen miles northwards of Poitiers an aërolite fell with a great detonation.

Does all that the shooting-stars contain, burn in the outermost strata of the atmosphere whose refracting power causes the phenomenon of twilight? The above-mentioned various colours, during the process of combustion, admit of the inference of a chemical difference in the substances. In addition to this, the forms of these fiery meteors are exceedingly variable; some form merely *phosphorescent lines* of such fineness and number, that Forster, in the winter of 1832, saw the sky illuminated by them with a feeble glow.[22] Many shooting-stars move merely as luminous points, and leave no tail behind them. The combustion, attended with rapid or

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[22] Forster's *Mémoire sur les Etoiles filantes*, p. 31.

slow disappearance of the tails, which are generally many miles in length, is so much the more remarkable, as the burning tails sometimes bend and sometimes move onwards. The shining for some hours of the tail of a fire-ball which had long disappeared, observed by Admiral Krusenstern and his companions during their voyage round the world, vividly calls to mind the *long shining* of the cloud from which the great aërolite of Ægos Potamos is said to have fallen, according to the certainly not quite trustworthy relation of Damachos. (*Cosmos*, vol. i. p. 122 and note.)

There are shooting-stars of very different magnitude increasing to the apparent diameter of Jupiter or Venus; on the occasion also of the fall of shooting-stars seen at Toulouse (April 10th, 1812), and the observation of a fire-ball at Utrecht, on the 23rd of August of the same year, they were seen to form, as it were, from a luminous *point*, to shoot out in a *starlike* manner, and then to expand to a sphere of the size of the Moon. In very abundant falls of meteors, such as those of 1799 and 1833, there have been undoubtedly many fire-balls, mixed with thousands of shooting-stars; but the *identity* of both kinds of fiery meteors has not been by any means proved hitherto. Relation is not identity. There still remains much to be investigated as to the physical relations of both; as to the influence pointed out by Admiral Wrangel,[23] of the shooting-stars upon the development of the *polar light* on the shores of the Frozen Sea; and as to the number of luminous processes indistinctly described, but not on that account to be hastily denied, which have preceded the formation of fire-balls. The greater number of fire-balls appear *unaccompanied* by shooting-stars, and show no periodicity in their appearance. What we know of shooting-stars, with regard to their divergence from definite points, is at present only to be applied to fire-balls with caution.

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[23] *Cosmos*, vol. i. p. 114 and note.

Meteoric stones fall the most rarely in a quite clear sky, without the previous formation of a black meteor-cloud, without any visible phenomenon of light, but with a terrible crackling, as upon the 6th of September, 1843, near Klein-Wenden, not far from Mühlhausen; or they fall, and this more frequently, shot out of a suddenly formed dark cloud, accompanied by phenomena of sound, though without light; finally, and indeed the most frequently, the falls of meteoric stones present themselves in close connection with brilliant fire-balls. Of this connection the falls of stones at Barbotan (Dép. des Landes) on the 24th of July, 1790, with a simultaneous appearance of a red fire-ball and a *white* meteoric cloud,[24] from which the aërolites fell; the fall of stones at Benares, in Hindostan, 13th December, 1798, and that of Aigle (Dép. de L'Orne), on the 26th of April, 1803, afford well-described and indubitable examples. The last of the phenomena here mentioned—that which among all has been investigated and described with the greatest care by Biot—has finally, 23 centuries after the great Thracian fall of stones, and 300 years since a Frate was killed by an aërolite at Crema,[25]

[24] Känitz, *Lehrbuch der Meteorologie*, vol. iii. p.277.

[25] The great fall of aërolites at Crema, and on the shores of Adda, is described with especial vivacity, but unfortunately in a rhetorical and vague manner, by the celebrated Petrus Martyr, of Anghiera (*Opus Epistolarum*, Amst. 1670, no. cccclxv. pp. 245–246). What preceded the fall itself was an almost total darkening on the 4th of September, 1511, at the noon hour. "Fama est, pavonem immensum in aërea Cremensi plaga fuisse visum. Pavo visus in pyramidem converti, adeoque celeri ab occidente in orientem raptari cursu, ut in horæ momento magnam hemisphærii partem, doctorum inspectantium sententia, pervolasse credatur. Ex nubium illico densitate tenebras ferunt surrexisse, quales viventium nullus unquam se cognovisse fateatur. Per eam noctis faciem, cum formidolosis fulguribus, inaudita tonitrua regionem circumsepserunt." "The report is, that an enormous peacock

put an end to the scepticism of the academists. A large fire-ball, which moved from S.E. to N.W., was seen at one o'clock in the afternoon at Alençon, Falaise, and Caen, while the sky was quite clear. Some moments afterwards there was heard near Aigle (Dép. de L'Orne), an explosion in a small, dark, almost motionless cloud, lasting for five or six minutes,

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was seen flying in the sky above the town of Crema. The peacock appeared to change into a pyramid, and was carried from west to east with such rapidity, that in a moment it seemed to traverse the whole hemisphere, as some learned men imagined who saw it. Immediately afterwards such darkness arose from the denseness of the clouds as was never known by mortal before. During this midnight gloom, unheard-of thunders, mingled with awful lightnings, resounded through that quarter of the heavens." The illuminations were so intense, that the inhabitants round Bergamo, could see the whole plain of Crema during the darkness. "Ex horrendo illo fragore quid irata natura in eam regionem pepererit, percunctaberis. Saxa demisit in Cremensi planitie (ubi nullus unquam æquans ovum lapis visus fuit) immensæ magnitudini, ponderis egregii. Decem fuisse reperta centilibralia saxa ferunt." "You will perhaps inquire what accompanied that terrific commotion of nature. On the plain of Crema, where never before was seen a stone the size of an egg, there fell pieces of rock of enormous dimensions and of immense weight. It is said that ten of these were found weighing a a hundred pounds each. Birds, sheep, and even fish were killed." Under all these exaggerations it may still be seen, that the *meteoric cloud* out of which the stones fell, must have been of uncommon blackness and thickness. The "pavo" was undoubtedly a long and broad-tailed fire-ball. The terrible noise in the *meteoric cloud* is here represented as the thunder accompanying the lightning (?). Anghiera himself received in Spain a fragment, the size of a fist (*ex frustris disruptorum saxorum*), and showed it to King Ferdinand the Catholic, in the presence of the famous warrior Gonzalo de Cordova. His letter ends with the words: "Mira super hisce prodigiis conscripta fanatice, physice, theologice ad nos missa sunt ex Italia. Quid portendant, quomodoque gignantur, tibi utraque

which was followed three or four times by a noise like a cannon and a rattle of muskets, mixed with a number of drums. At each explosion parts of the vapour, of which the cloud consisted, were removed. No appearance of light was visible in this instance. There fell at the same time upon an elliptical surface, whose major axis, from S.E. to N.W., had a length of 6 miles, a great number of meteoric stones, the largest of which weighed only 17½ pounds. They were hot but not red,[26] smoked visibly, and, what is very striking,

servo, si aliquando ad nos veneris." "From these prodigies Italy has furnished us with many a marvel of superstition, physic, and theology; what they portend, and how they are to come to pass, you will learn whenever you come to us." (Written from Burgos to Fagiardus.) Cardanus (*Opera*, ed. Ludg. 1663, tom. iii. lib. xv. cap. lxxii. p. 279,) affirms still more accurately, that 1200 aërolites fell among them, one of 120 pounds weight, iron grey, of great density. The noise is said to have lasted two hours: "ut mirum sit, tamtam molem in aëre sustineri potuisse;" "it is marvellous that such a mass could be supported in the air." He considered the tailed fire-ball to be a comet, and errs in the date of the phenomenon by a year: "Vidimus anno 1510." Cardanus was at that time nine or ten years old.

[26] Recently, on the occasion of the fall of aërolites at Braunau (July 14th, 1847), the fallen masses of stone were so hot, that after six hours they could not be touched without causing a burn. I have already treated (*Asie Centrale*, tom. i. p. 408) of the analogy which the Scythian *myth of sacred gold* presents with a fall of meteors. "5. As the Scythians say, theirs is the most recent of all nations; and it arose in the following manner. The first man that appeared in this country, which was a wilderness, was named Targitaus: they say that the parents of this Targitaus, in my opinion relating what is incredible,—they say, however, that they were Jupiter and a daughter of the river Borysthenes; that such was the origin of Targitaus: and that he had three sons, who went by the names of Lipoxais, Apoxais, and the youngest, Colaxais; that during their

they were more easily broken during the first day after the fall than subsequently. I have intentionally given more time to this phenomenon, in order to be able to compare it with another of the 13th of September, 1768. About half-past four o'clock in the afternoon of the above-mentioned day, a dark cloud was seen near the village of Lucé (Dép. d'Eure et Loire) 4 miles westward of Chartres, in which a noise was heard like a cannon shot, and at the same time a hissing was perceived in the air caused by the fall of a black stone moving in a curve. The stone, which had penetrated into the Earth, weighed 7½lbs., and was so hot that it could not be touched. It was very imperfectly analyzed by Lavoisier, Fougeroux, and Cadet. No phenomena of light were perceived throughout the whole occurrence.

As soon as the observation of periodic falls of shooting stars was commenced, and their appearance on certain nights expected, it was remarked that the frequency of the meteors

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reign a plough, a yoke, an axe, and a bowl of golden workmanship dropping down from heaven, fell on the Scythian territory; that the eldest, seeing them first, approached, intending to take them up, but as he came near, the gold began to burn; when he had retired the second went up, and it did the same again; accordingly the burning gold repulsed these; but when the youngest went up the third, it became extinguished, and he carried the things home with him; and that the elder brothers in consequence of this giving way, surrendered the whole authority to the youngest. 6. From Lipoxais, *they say*, are descended those Scythians who are called Auchatæ; from the second, Apoxais, those who are called Catiari and Traspies; and from the youngest of them, the royal race, who are called Paralatæ. But all have the name of Scoloti, from the surname of their king; but the Grecians call them Scythians. 7. The Scythians say that such was their origin; and they reckon the whole number of years from their first beginning, from king Targitaus to the time that Darius crossed over against them, to be not more than a

increased with the length of time from midnight, and that the greatest number fell between two and five in the morning. Already, on the occasion of the great fall of meteors at Cumana in the night of the 11th and 12th of November, 1799, my fellow-travellers saw the greatest swarm of shooting stars between half-past two and four o'clock. A very meritorious observer of the phenomena of meteors, Coulvier-Gravier, contributed an important essay to the Institute at Paris, upon *la variation horaire des étoiles filantes*. It is difficult to conjecture the cause of such an *hourly variation*, an influence of the distance from the hour of midnight. If under different meridians the shooting stars do not become especially visible until a certain early hour, then, in the case of their cosmical origin, we must assume what is still but little probable; viz. that these night, or rather early morning hours, are especially adapted to the ignition of the shooting stars, while in other

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thousand years, but just that number. This sacred gold the kings watch with the greatest care, and annually approach it with magnificent sacrifices to render it propitious. If he who has the sacred gold happens to fall asleep in the open air on the festival, the Scythians say he cannot survive the year, and on this account they give him as much land as he can ride round on horseback in one day. The country being very extensive, Colaxais established three of the kingdoms for his sons, and made that one the largest in which the gold is kept. The parts beyond the north of the inhabited districts the Scythians say can neither be seen nor passed through, by reason of the feathers shed there; for that the earth and air are full of feathers, and that it is these which intercept the view." *Herodotus*, iv. 5 and 7; (Translation, Bohn's Classical Library, p. 238.) But is the *myth of sacred gold*, merely an ethnographical myth; an allusion to three king's sons, the founders of three races of Scythians? an allusion to the prominent position which the race of the youngest son, the Paralatæ, attained? (Brandstätter, *Scythica, de aurea caterva*, 1837, pp. 69 and 81.)

hours of the night more shooting stars pass by before midnight invisible. We must still long and patiently collect observations.

The principal characters of the solid masses which fall from the air, I believe I have treated of with tolerable completeness (*Cosmos*, vol. I. p. 117.) in reference to their chemical relations and the granular structure, especially investigated by Gustav Rose in accordance with the state of our knowledge in the year 1845. The successive labours of Howard, Klaproth, Thénard, Vauquelin, Proust, Berzelius, Stromeyer, Laugier, Dufresnoy, Gustav and Heinrich Rose, Boussingault, Rammelsberg, and Shepard, have afforded a rich material,[27] and yet two-thirds of the fallen meteoric stones, which lie at the bottom of the sea, escape our observation. Although it is striking that under all zones, at points most distant from each other, the aërolites have a certain *physiognomic* resemblance—in Greenland, Mexico and South America, in Europe, Siberia and Hindostan—still upon a closer investigation they present very great differences. Many contain $\frac{96}{100}$ of iron, others (Siena) scarcely $\frac{2}{100}$; nearly all have a thin black brilliant and at the same time veined coating: in one (Chantonnay) this crust was entirely wanting. The specific gravity of some meteoric stones amounts to as much as 4·28, while the carbonaceous stone of Alais, consisting of crumbling lamelæ, showed a specific gravity of only 1·94. Some (Juvenas) have a doleritic structure, in which crystallized olivin, augite and anorthite are to be recognized separately; others (the masses of Pallas) afford merely iron, containing nickel and olivin; and others again (to judge from the proportions of the ingredients) are

[27] The metals discovered in meteoric stones are, nickel by Howard, cobalt by Stromeyer, copper and chromium by Laugier, tin by Berzelius.

aggregates of hornblende and albite (Chateau-Renard), or of hornblende and labrador (Blansko and Chantonnay).

According to the general summary of results given by a sagacious chemist, Professor Rammelsberg, who has recently occupied himself uninterruptedly, and as actively as successfully, with the analysis of aërolites and their composition from simple minerals, "the separation of the masses fallen from the air into *meteoric iron* and *meteoric stones* is not to be admitted in its strictest sense. Meteoric iron is sometimes found, though seldom, with *silicates* intermixed (the Siberian mass weighed again by Heis of 1270 Russian pounds, with grains of olivin), and on the other hand many meteoric stones contain *metallic iron.*

"A. The *meteoric iron*, whose fall it has been possible to observe only a few times (Hradschrina, near Agram, on the 26th of May, 1751, Braunau, 14th of July, 1847), while most analogous masses have already laid long upon the surface of the earth, possesses in general very similar physical and chemical properties. It almost always contains sulphuret of iron mixed with it in finer or coarser particles, which, however, do not appear to be either iron pyrites or magnetic pyrites, but a sulphuret of iron.[28] The principal mass of such a meteoric iron is also not pure metal, but consists of an *alloy* of *iron* and *nickel*, so that this constant presence of nickel (on the average 10 per cent. sometimes rather more, sometimes rather less) serves justly as an especial criterion for the *meteoric* nature of the whole mass. It is only an *alloy of two isomorphous* metals, not a combination in definite proportions. There are also present in minute quantity: cobalt, manganese, magnesium, copper, and carbon. The last-mentioned substance is partly mixed mechanically, as difficultly combustible graphite;

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[28] Rammelsberg, in Poggendorff, *Annalen*, vol. lxxiv. 1849, p. 442.

partly in chemical combination with iron, and therefore analogous to many kinds of bar-iron. The principal mass of the meteoric iron contains also always a peculiar combination of *phosphorus with iron and nickel*, which on the solution of the iron in hydrochloric acid, remains in the form of silver-white, microscopic, crystalline needles and laminæ.

"B. The *meteoric stones*, properly so called, it is customary to divide into *two classes*, according to their external appearance. The stones of one class present, in an apparently homogeneous mass, grains and splinters of *meteoric iron*, which are attracted by the magnet, and possess entirely the nature of that found in larger masses. To this class belong, for example, the stones of Blansko, Lissa, Aigle, Ensisheim, Chantonnay, Klein-Wenden near Nordhausen, Erxleben, Château-Renard, and Utrecht. The stones of the other class are free from metallic *admixtures*, and present rather a *crystalline* mixture of different mineral substances; as, for example, the stones of Juvenas, Lontalax, and Stannern.

"Since the time that Howard, Klaproth, and Vauquelin first instituted the chemical investigation of meteoric stones, for a long time no regard was paid to the fact that they might be mixtures of separate combinations; but they were examined only for their total constituents, and it was considered sufficient to draw out the iron by the magnet. After Mohs had directed attention to the analogy between some aërolites and certain telluric rocks, Nordenskjöld endeavoured to prove that the aërolite of Lontalax in Finland consisted of olivin, leucite, and magnetic iron ore; but the beautiful observations of Gustav Rose first placed it beyond doubt that the stone of Juvenas consists of magnetic pyrites, augite, and a feldspar, very much resembling labrador. Guided by this, Berzelius endeavoured, in a more extended essay (*Kongl. Vetenskaps-Academiens Handlingar für* 1834), to eliminate also by chemical methods the mineralogical nature of the separate combina-

tions in the aërolites of Blansko, Chantonnay and Alais. The road happily pointed out by him beforehand has subsequently been abundantly followed.

"*a*. The first and more numerous class of *meteoric stones*, those with metallic iron, contain this disseminated through them, sometimes in larger masses, which occasionally form a skeleton, and thus constitute the transition to those meteoric masses of iron in which, as in the Siberian mass of Pallas, the other materials disappear more considerably. On account of the constant *presence of olivin*, they are rich in magnesia. The olivin is that part of the meteoric stone which is decomposed when it is treated with acids. Like the telluric, it is a silicate of magnesia and protoxide of iron. That part which is not attacked by acids is a mixture of feldspathic and augitic matter, whose nature admits of being determined solely by calculation from its total constituents, as labrador, hornblende, augite, or oligoclas.

"*β* The second much rarer class of meteoric stones have been less examined. They contain partly magnetic iron ore, olivin, and some feldspathic and augitic matter; some of them consist merely of the two last mentioned simple minerals, and the feldspar tribe is then represented by anorthite.[30] *Chrome iron ore* (oxide of chromium and protoxide of iron) is found in small quantity in all meteoric stones; *phosphoric acid* and *titanic acid*, which Rammelsberg discovered in the very remarkable stone of Juvenas, perhaps indicate *apatite* and *titanite*.

"Of the *simple substances* hitherto detected in the meteoric stones, there are 18:[31] *oxygen*, *sulphur*, *phosphorus*, *carbon*,

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[30] Shepard, in *Silliman's American Journal of Science and Arts*, ser. ii. vol. ii. 1846, p. 377; Rammelsberg, in Poggend. *Ann*. Bd. lxxiii. 1848, p. 377.

[31] Compare *Cosmos*, vol. i. p. 118.

silicium, aluminum, magnesium, calcium, potassium, sodium, iron, nickel, cobalt, chromium, manganesium, copper, tin, and *titanium*. The *proximate* constituents are: (*a*) *metallic:* nickel-iron, a combination of phosphorus with iron and nickel, sulphuret of iron and magnetic pyrites; (*b*) *oxidized:* magnetic iron ore and chrome iron ore; (*c*) *silicates:* olivin, anorthite, labrador and augite."

In order to concentrate the greatest number of important facts separated from hypothetic conjectures, it still remains for me to develop the manifold analogies which some meteoric stones present as *rocks* with older, so-called trap rocks, (dolerites, diorites, and melaphyren), with basalts and more recent lava. These analogies are so much the more striking, as "the metallic alloy of nickel and iron, which is constantly contained in certain meteoric masses," has not hitherto been discovered in telluric minerals. The same distinguished chemist whose friendly communications I have made use of in these last pages, enters fully into this subject in a special treatise,[32] the results of which will be more appropriately discussed in the geological part of the Cosmos.

[32] *Zeitschrift der deutschen geolog. Gesellschaft*, Bd. i. p. 232. All the matter in the text from p. 593 to p. 596, which is between inverted commas, was taken from the manuscript of Professor Rammelsberg (May, 1851).

Conclusion.

In concluding the *uranological* part of the *physical description of the Universe*, in taking a retrospect of what I have *attempted* (I do not say *accomplished*), after the execution of so difficult an undertaking, I think it necessary once more to call to mind that this execution could have been effected only under those conditions which have been indicated in the *Introduction* to the third volume of *Cosmos*. The attempt to carry out such a cosmical treatment of the subject is limited to the representation of space and its material contents, whether aggregated into spheres or not. The character of the present work differs therefore essentially from the more comprehensive and excellent *elementary works on astronomy* which the various literatures of modern times possess. *Astronomy*, as a *science*, the triumph of mathematical reasoning, based upon the sure foundation of the doctrine of gravitation and the perfection of the higher analysis (a mental instrument of investigation), treats of *phenomena of motion* measured according to *space* and *time*; locality (position) of the cosmical bodies in their mutual and perpetually-varying relations to each other; *change of form*, as in the *tailed* comets; change of light, as the *sudden appearance* or total *extinction* of the *light* of distant suns. The quantity of matter present in the universe remains always the same; but from what has already been discovered in the telluric sphere of physical laws of nature, we see working in the eternal *round of material phenomena* an ever-unsatisfied *change*, presenting itself in numberless and nameless *combinations*. Such an exercise of force by matter is called forth by

its at least apparent *heterogeneity*. Exciting *motion in immeasurably minute spaces*, this heterogeneity of matter complicates all the problems of *terrestrial* phenomena.

The *astronomical* problems are of a simpler nature. Hitherto unencumbered by the above-mentioned complications, directed to the consideration of the *quantities* of ponderable matter (*masses*), to the *oscillations* producing *light* and *heat*—the *mechanics of the heavens* has, precisely on account of this simplicity, in which everything is reduced to *motion*, remained in all its branches amenable to mathematical treatment. This advantage gives to the elementary works on *theoretical* astronomy a great and entirely peculiar charm. In them is reflected what the intellectual labours of later centuries have achieved by the analytical methods; how configuration and orbits are determined; how in the phenomena of planetary motion only small oscillations about a *mean* condition of equilibrium can take place; how the planetary system, from its *internal* arrangement, works its preservation and permanence by the *compensation* of *perturbations*.

The examination of the *means* of forming a general conception of the universe, the *explanation* of the complicated celestial phenomena, do not belong to the plan of this work. The physical description of the universe relates to what fills space, and organically animates it, in both spheres of uranological and telluric relations. It adheres to the consideration of the discovered laws of nature, and treats of them as acquired facts, as immediate results of empirical induction. In order to carry out the work of the *Cosmos* within the appropriate limits, and not with too great extension, it must not be attempted to establish theoretically the connection of phenomena. In this limitation of the plan laid down beforehand, I have, in the astronomical volume of *Cosmos*, applied so much the more care to the individual facts and their arrangement. From the consideration of universal space, its temperature,

the degree of its transparency, and the resisting medium which fills it, I have passed on to natural and telescopic vision, the limits of visibility, the velocity of light, according to the difference of its sources, the imperfect measurements of luminous intensity, and the new optical means of distinguishing direct from reflected light. Then follows the heaven of fixed stars; the numerical statement of its self-luminous suns so far as their position is determined; their probable distribution; the changeable stars which reappear at well-defined periods; the proper motion of the fixed stars; the assumption of the existence of dark cosmical bodies, and their influence upon the motion of the binary stars; the nebulous spots, in so far as these are not remote and very dense swarms of stars.

The transition from the sidereal part of uranology from the heaven of the fixed stars to our solar system, is merely a transition from the universal to the particular. In the class of binary stars, self-luminous cosmical bodies move about a common centre of gravity. In our solar system, which is constituted of very heterogeneous elements, dark cosmical bodies revolve round a self-luminous one, or much rather again round a common centre of gravity, which at different times is situated within and without the central body. The individual members of the solar system are of dissimilar nature—more dissimilar than for many centuries astronomers were justified in supposing. They are principal and secondary planets; among the principal planets a group whose orbits intersect each other; an innumerable host of comets; the ring of the zodiacal light; and, with much probability, the periodic meteor-asteroids.

It still remains to state here fully, as actual relations, the three great laws of planetary motion, discovered by Kepler. —*First law:* each orbit of a planetary body is an ellipse, in one of whose foci the Sun is situated.—*Second law:* each

planetary body describes in equal times equal sectors round the Sun.—*Third law:* the squares of the times of revolution of two planets, are as the cubes of their mean distances. The second law is sometimes called the first, because it was discovered earlier. (Kepler, *Astronomia nova, seu Physica cœlestis, tradita commentariis de motibus stellæ Martis, ex observ. Tychonis Brahi elaborata,* 1602; compare cap. xl. with cap. lix.) The first two laws would be applicable, if there were only a single planetary body; the third and most important which was discovered *nineteen* years afterwards, fixes the motions of two planets to one law. (The manuscript of the *Harmonice Mundi,* which appeared in 1619, was already completed on the 27th of May, 1618.)

While the laws of planetary motions were empirically discovered at the commencement of the seventeenth century; while Newton first discovered the force, of whose action Kepler's laws were to be considered as necessary consequences; so the end of the eighteenth century has had the merit of demonstrating the *stability of the planetary system* by the new path which the perfected calculation of infinitesimals opened to the investigation of astronomical truths. The principal elements of this stability are: the invariability of the major axes of the planetary orbits, proved by Laplace (1773 and 1784), Lagrange, and Poisson; the long periodic change (comprised within narrow limits) of the eccentricity of two larger planets more distant from the sun, Jupiter and Saturn, themselves only $\frac{1}{1048}$ of the mass of the all-governing central body; finally, the arrangement that, according to the eternal plan of creation, and the nature of the formation of the planets, they have all a translatory and rotatory motion in one direction; that this motion takes place in orbits of slight and but little varying ellipticity, in planes of moderate differences of inclination; and that the periods of the planetary revolutions have among each other no common measure. Such elements

of stability, as it were the maintenance and duration of the planets' existence, are dependent upon the condition of mutual action with a separate circle. If by the entry of a cosmical body *coming from without*, and not previously belonging to the planetary system, that condition was disturbed (Laplace, *Expos. du Syst. du Monde*, pp. 309 and 391), then this disturbance, as the consequence of new attractive forces, or of a collision, might certainly become destructive to the existing system, until finally, after long conflict, a new equilibrium was produced. The arrival of a comet upon an hyperbolic orbit from a great distance, even when want of mass is made up for by immense velocity, can excite apprehension only in an imagination which is not susceptible of the earnest assurances of the calculation of probabilities. The wandering clouds of the *interior comets* are not more dangerous to our solar system than the great inclination of the orbits of some of the *small planets* between Mars and Jupiter. Whatever must be characterized as mere probability, lies beyond the domain of a *physical* description of the universe; science must not wander into the cloud-land of cosmological dreams.

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